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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

A PERFORMANCE ANALYSIS OF THE APOLLO UNIFIED S-BAND COMMUNICATIONS SYSTEM FOR A TYPICAL LUNAR MISSION

INFORMATION SYSTEMS DIVISION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

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A PERFORMANCE ANALYSIS OF THE APOLLO UNIFIED S-BAND COMMUNICATIONS SYSTEM FOR A TYPICAL LUNAR MISSION

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LIST OF ABBREVIATIONS AND SYMBOLS

AOS	Acquisition of signal
BC	Best case
BER	Bit error rate (Ratio of total errors to total bits)
BU	Back-up
CSM	Command and service module
db	Decibel
dbw	Decibel referenced to 1 watt
EMU	Extravehicular mobility unit
FM	Frequency modulation
GLD	Goldstone
GMT	Greenwich mean time
HL	Hard line
Hz	Hertz
IAM	Incidental amplitude modulation
IESD	Instrumentation and Electronic Systems Division .
IF	Intermediate frequency
IPM	Incidental phase modulation
ISD	Information Systems Division
Kbps	Kilobits per second
LM	Lunar module
LOI	Lunar orbit injection
LOS	Loss of signal
LPF	Low-pass filter
MBW	Medium beam width
MILA	Merritt Island Launch Area
MSC	Manned Spacecraft Center
MSFN	Manned Space Flight Network
NBW	Narrow beam width
NC	Nominal case
nm	Nautical miles
P&I	Performance and interface
P_c	Received carrier power
PLL	Phase locked loop
PM	Phase modulation
PRN	Pseudorandom noise
Rad	Radian
RF	Radio frequency
SC	Spacecraft
SCN	Specification Change Notice
SNR	Signal-to-noise ratio
SNR_{act}	Actual signal-to-noise ratio

LIST OF ABBREVIATIONS AND SYMBOLS (Continued)

SNR_{req}	Required signal-to-noise ratio
TEC	Transearth coast
TEI	Transearth injection
TLC	Translunar coast
TLI	Translunar injection
TLM	Telemetry
T&D	Telemetry and data
TV	Television
USB	Unified S-band
WBW	Wide beam width
WC	Worst case
°K	Degrees Kelvin
Af	Peak frequency deviation
β	Modulation index
$2\beta lo$	Two-sided carrier loop noise bandwidth

1.0 Summary

The purpose of this report is to define the conditions under which the Apollo Unified S-Band System will provide adequate communications during a lunar mission. To achieve this purpose, a time-line of expected communication performance, based on a typical lunar mission trajectory, is calculated and graphically presented.

The concept of communication circuit margins is used as the criteria for predicting system performance. Specified values of system parameters are used in all circuit margin calculations. Performance predictions for the CSM omni modes are based on full-scale omni antenna patterns. Predictions for LM omni modes are based on a -3 db omni antenna gain. The margins are optimistic in that second-order effects such as incidental phase modulation (IPM), finite transmitted signal-to-noise ratios, etc, are assumed to produce no degradation. These second-order effects and their potential degradations to the communication system are discussed in the appendices.

Results of this analysis indicate that the following modes have negative margins at lunar distance under worst case conditions:

(1) Two PM contingency modes (CSM Mode 8 and LM Mode 4), which have simultaneous low bit rate telemetry and back-up voice. These modes are to be used when the high-gain antenna is not available.

(2) Three FM modes (CSM Modes 1 and 2, which have playback voice and telemetry, and CSM Mode 4 with television).

In addition, the CSM down-link PRN contingency modes 7 and 9 have positive margins only if the up-link is limited to PRN ranging information. All other FM and PM modes, when used in the normal antenna and power configuration, have positive circuit margins throughout the mission.

CSM PM Mode 8, which provides simultaneous 1.6 Kbps telemetry and voice, has negative margins for a large percentage of the time during lunar orbit. These margins are based on achieving a 10^{-3} bit error rate in the telemetry channel, and 70-percent word intelligibility in the voice channel. It is possible, by constraining the spacecraft attitude to obtain sufficient omni gain, to ensure positive margins for the total time. However, experimental results, as given in Appendix D, indicate that telemetry performance in the PM contingency modes may be severely degraded due to voice interference.

LM PM Mode 4 is directly analogous to CSM Mode 8 as discussed above. The LM margins are negative, based on calculations using a -3 db omni antenna gain. If fuel is not available for attitude constraints to favor an omni antenna element, it will be necessary to revert to modes with voice or telemetry only.

CSM FM Modes 1, 2, and 4 (32:1 and 1:1 playback of CSM voice and telemetry, and TV) exhibit negative mode-as-a-whole margins at lunar distance under worst case conditions. An improvement in system performance is necessary to make these margins positive. Two possible MSFN improvements are to increase the worst case antenna gain of the 85-foot MSFN stations to 52.5 db, and to extend threshold of the FM demodulator in the ground receiver as has been requested by MSC. Increasing the SC output power and/or reducing SC circuit losses are SC improvements that have been requested. However, slightly positive circuit margins based on an 8 db mode-as-a-whole requirement do not necessarily ensure satisfactory performance. A discussion of expected FM performance is given in Appendix C.

Circuit margins for required CSM and LM up-link modes are positive except for sim ltaneous transmission of up-data and voice to the LM at lunar using the omni antenna.

Tables 1-1 through 1-4 summarize the lunar distance circuit margins for all down-link and up-link modes considered in this report. The down-link PRN modes are calculated assuming a full up-link (PRN, voice, updata). No turn-around modulation is present on down-link modes without PRN ranging. The antenna transmitting power configurations were chosen to provide the minimum positive circuit margins. That is, if a mode has positive margins using the spacecraft low power output and high-gain antenna, similar data is not presented for the high power output and for high-gain antenna.

TABLE 1-1

CSM DOWN-LINK MODE SUMMARY***

Mode	Service(s)	Circuit Margin (db) 215,000 nm		Antenna		Transmit Power		Criteria
		Nominal	Worst †	SC	MSFN	SC	MSFN	
CSM PM Mode 1	(1) Voice/ Biomed (2) 51.2Kbps TLM	(1) 5.0 (2) 4.2	(1) 3.0 (2) 2.3	High-gain NBW	30-foot	High	N/A	90% word intelligibility 10^{-6} BER TLM
CSM PM Mode 2	PRN Ranging* (1) Voice/ Biomed (2) 51.2Kbps TLM	(1) 4.3 (2) 3.5	(1) 1.3 (2) 0.4	High-gain NBW	85-foot	Low	High	60-sec PRN Code Acquisition
		(1) 4.4 (2) 3.5	(1) 2.5 (2) 1.7	High-gain NBW	30-foot	High	High	90% word intelligibility 10-6 BER TLM
CSM PM Mode 3	PRN Ranging (1) Voice/ Biomed (2) 1.6Kbps TLM	(1) 4.4 (2) 6.6	(1) 3.4 (2) 5.8	High-gain NBW	30-foot	Low	High	Same as Mode 2
CSM PM Mode 5	1.6Kbps TLM	5.8**	2.9**	Zero-db Omni	85-foot	High	N/A	10^{-3} BER
CSM PM Mode 6	Emergency Key	5.7**	2.8**	Zero-db Omni	85-foot	Bypass	N/A	20 characters per minute 60% copying accuracy
CSM PM Mode 7	PRN Ranging	10.6	8.1	Zero-db Omni	85-foot	High	High	60-sec PRN Code Acquisition
CSM PM Mode 8	(1) Voice (2) 1.6Kbps TLM	(1) 2.1** (2)+3.6	(1)-0.8** (2)+.7	Zero-db Omni Zero-db Omni	85-foot	High	N/A	70% word intelligibility 10^{-3} BER TLM
CSM PM Mode 9	PRN Ranging 1.6Kbps TLM	3.8 4.6	1.3 1.7	Zero-db Omni	85-foot	High	High	60-sec PRN Code Acquisition 10-3 BER TLM
CSM PM Mode 10	Voice	9.6	6.7	Zero-db Omni	85-foot	High	N/A	70% word intelligibility
CSM FM Mode 1	1:1 Playback of: Voice CSM 51.2 Kbps TLM	2.6	-1.4	High-gain NBW	85-foot	High	N/A	Mode-as-a-whole requirement 8.0db 4-MHz IF bandwidth

†Worst case modulation index tolerances not included in calculations for modes with multiple information channels.

*All margins for PRN modes in this table are positive.

**See margin plots in section 3.0 for actual range of values.

***Predicted using theoretical mathematical model and Performance and Interface Specification Parameters.

TABLE 1-1 (Continued)***

Mode	Service(s)	Circuit Margin (db) 215,000 nm		Antenna		Transmit Power		Criteria
		Nominal	Worst †	SC	MSFN	SC	MSFN	
CSM FM Mode 2	32:1 Play-back of: Voice 1.6Kbps TLM	2.6	-1.4	High-gain	85-foot	High	N/A	Same as FM Mode 1
CSM FM Mode 3	32:1 Play-back of: LM Split-Phase TLM	8.6	4.6	High-gain NBW	85-foot	High	N/A	Mode-as-a-whole requirement 8. Odb 1-MHz IF bandwidth
CSMFM Mode 4	TV	2.6	-1.4	High-gain NBW	85-foot	High	N/A	Same as FM Mode 1

†Worst case modulation index tolerances not included in calculations for modes with multiple information channels.
*All margins for PRN modes in this table are positive.
**See margin plots in section 3. 0 for actual range of values.
***Predicted using theoretical mathematical model and Performance and Interface Specification Parameters.

TABLE 1-2

LM DOWN-LINK MODE SUMMARY***

Mode	Service(s)	Circuit Margin (db) 215,000 Nominal	Worst †	tenna SC	MSFN	Transmit Power SC	MSFN	Criteria
LM PM Mode 1	(1) Voice/HL Biomed (2) 51.2Kbps TLM	(1) 4.0 (2) 1.7	(1) 1.8 (2) -0.4	Steerable	30-foot	High	N/A	90% word intelligibility 10^{-6} BER TLM
		(1) 11.1 (2) 8.7	(1) 9.3 (2) 6.2	Erectable	30-foot	High	N/A	
		(1) 9.6 (2) 7.3	(1) 6.5 (2) 4.2	Steerable	85-foot	High	N/A	
LM PM Mode 2	PRN Ranging* (1) Voice/HL Biomed (2) 51.2Kbps TLM	(1) 3.4 (2) 1.1	(1) 1.3 (2) -1.2	Steerable	30-foot	High	High	60-sec. PRN code acquisition time 90% word intelligibility 10^{-6} BER TLM
		(1) 10.6 (2) 8.2	(1) 7.0 (2) 4.2	Erectable	30-foot	High	High	
		(1) 9.8 (2) 7.3	(1) 5.8 (2) 3.5	Steerable	85-foot	High	High	
LM PM Mode 3	1.6Kbps TLM	5.7	0.7	-3db Omni	85-foot	High	N/A	10^{-3} BER TLM
LM PM Mode 4	(1) Voice (2) 1.6Kbps TLM	(1) 3.8 (2) 4.4	(1) -0.3 (2) 0.3	-3db Omni	85-foot	High	N/A	10^{-3} BER TLM 70% word intelligibility
LM PM Mode 5	Voice	7.8	1.5	-3db Omni	85-foot	High	N/A	70% word intelligibility
LM PM Mode 6	Emergency Key	10.5	6.3	-3db Onini	85-foot	Low	N/A	20 characters per niin. 60% copying accuracy
LM PM Mode 7	(1) Voice/HL Biomed/ EMU (2) 1.6Kbps TLM	(1) 7.5 (2) 8.6	(1) 3.8 (2) 5.3	Erectable	85-foot	LOW	N/A	90% word intelligibility 10^{-6} BER TLM
LM PM Mode 8	(1) Voice (2) 1.6Kbps TLM (3) HL Biomed (4) EMU #1 -#7	(1) 6.4 (2) 12.0 (3) 8.6 (4) >12.5	(1) 2.8 (2) 7.5 (3) 4.5 (4) >9.0	Erectable	85-foot	LOW	N/A	70% word intelligibility 10^{-6} BER TLM
		(1) 13.1 (2) 18.7 (3) 14.9 (4) >19.2	(1) 9.8 (2) 15.2 (3) 11.8 (4) >16.0	Steerable	85-foot	High	N/A	
LM FM Mode 9A	Voice/EMU/HL Biomed 1.6Kbps TLM	0.3	-4.2	Steerable	85-foot	High	N/A	Mode-as-a-whole requirement 8.0db in 4-MHz IF bandwidth

†Worst case modulation index tolerances not included in calculations for modes with multiple information channels.

*All margins for PRN modes shown here are positive.

***Predicted using theoretical mathematical model and Performance and Interface Specification Parameters.

TABLE 1-2 (Continued)***

Mode	Service(s)	Circuit Margin (db) 215,000 nm Nominal	Worst †	Antenna SC	Antenna MSFN	Transmit Power SC	Transmit Power MSFN	Criteria
LM FM Mode 9B	Voice/EMU/HL Biomed 51.2Kbps TLM	0.3	-4.2	Steerable	85-foot	High	N/A	Mode-as-a-whole requirement 8.0db in 4-MHz IF bandwidth
LM FM Mode 10A	Voice/EMU/HL Biomed 1.6Kbps TLM TV							
LM FM Mode 10B	Voice/EMU/HL Bioined 51.2Kbps TLM TV							
LM FM Mode 9A	Voice/EMU/HL Biomed 1.6Kbps TLM	8.8	4.4	Erectable	85-foot	High	N/A	Mode-as-a-whole requirement 8.0db in 4-MHz IF bandwidth
LM FM Mode 9B	Voice/EMU/HL Biomed 51.2Kbps TLM							
LM FM Mode 10A	Voice/EMU/HL Biomed 1.6Kbps TLM TV							
LM FM Mode 10B	Voice/EMU/HL Biomed 51.2Kbps TLM TV							

†Worst case modulation index tolerances not included in calculations for modes with multiple information channels.
*All margins for PRN modes shown here are positive.
***Predicted using theoretical mathematical model and Performance and Interface Specification Parameters.

TABLE 1-3

CSM UP-LINK MODE SUMMARY***

Mode	Service(s)	Circuit Margin (db) 215,000 nm Nominal	Worst *	Antenna SC	Antenna MSFN	Transmit Power MSFN	Criteria
CSM Mode 1	PRN Ranging**		--				
CSM Mode 2	Voice	11	8 8	Zero-db Omni	85-foot	High	90% word intelligibility
CSM Mode 3	Up-Data	11	8	Zero-db Omni	85-foot	High	Maximum message rejection rate of 1 per 1000

*Values shown are to the nearest db.
**Up-Link Ranging margins are not defined since the channel performance is based on a two-way link.
***Predicted using theoretical mathematical model and Performance and Interface Specification Parameters.

TABLE 1-3 (Continued)***

Mode	Service(s)	Circuit Margin (db) 215,000 nm Nominal	Circuit Margin (db) 215,000 nm Worst*	Antenna SC	Antenna MSFN	Transmit Power MSFN	Criteria
CSM Mode 4	PRN Ranging** Voice	-- 6	-- 4	Zero-db Omni	85-foot	High	90% word intelligibility
CSM Mode 5	PRN Ranging** Up-Data	6	-- 4	Zero-db Omni	85-foot	High	Maximum message rejection rate of 1 per 1000
CSM Mode 6	PRN Ranging** (1) Voice (2) Up-Data	-- (1) 3 (2) 0	-- (1) 2 (2)-1	Zero-db Omni	85-foot	High	90% word intelligibility Maximum message rejection rate of 1 per 1000
CSM Mode 7	(1) Voice (2) Up-Data	(1) 6 (2) 6	(1) 4 (2) 4	Zero-db Omni	85-foot	High	90% word intelligibility Maximum message rejection rate of 1 per 1000
CSM Mode 8	Back-Up Voice	11	8	Zero-db Omni	85-foot	High	90% word intelligibility

*Values shown are to the nearest db.
**Up-Link Ranging margins are not defined since the channel performance is based on a two-way link.
***Predicted using theoretical mathematical model and Performance and Interface Specification Parameters.

TABLE 1-4

***

Mode	Service(s)	Circuit Margin (db) 215,000 nm Nominal	Circuit Margin (db) 215,000 nm Worst*	Antenna SC	Antenna MSFN	Transmit Power MSFN	Criteria
LM Mode 1	PRN Ranging**	---	---	-3db Omni	85-foot	High	
LM Mode 2	Voice	11	7	-3db Omni	85-foot	High	90% word intelligibility
LM Mode 3	PRN Ranging** Voice	--- 6	--- 4	-3db Omni	85-foot	High	90% word intelligibility

*Values shown are to the nearest db.
**Up-Link ranging margins are not defined since the channel performance is based on a two-way link.
***Predicted using theoretical mathematical model and Performance and Interface Specification Parameters.

2.0 Introduction

The Block II Apollo Unified S-Band Communication System is designed to provide a variety of communication and ranging functions at slant ranges up to and including lunar distances. It is the purpose of this report to define the conditions under which this system will provide adequate communications, and to point out possible communication problem areas during a lunar mission. To this end, a timeline of expected communication performance is calculated and graphically presented for a typical lunar mission.

2.1 Circuit Margin Definition

The concept of communication circuit margins is used throughout this report as the criteria for predicting system performance. A circuit margin is defined as the difference in decibels between the required signal-to-noise ratio (SNR_{req}) and the actual signal-to-noise ratio (SNR_{act}), calculated in the predetection* bandwidth of the channel concerned. For example, in the telemetry (TLM) data channel the circuit margin is defined by

$$\text{Circuit Margin (TLM)} = SNR_{act}\ (\text{TLM}) - SNR_{req}\ (\text{TLM})$$

Figures 2-1 and 2-2 are simplified block diagrams of the USB MSFN and spacecraft (SC) receivers showing the points at which the circuit margins presented in this report are calculated. The criteria used to specify the required SNR in each information channel are taken from the applicable CSM or LM performance and interface specification (changes are included through SCN #19 for the CSM and SCN #10 for the LM). These values are listed in Table 2-1.

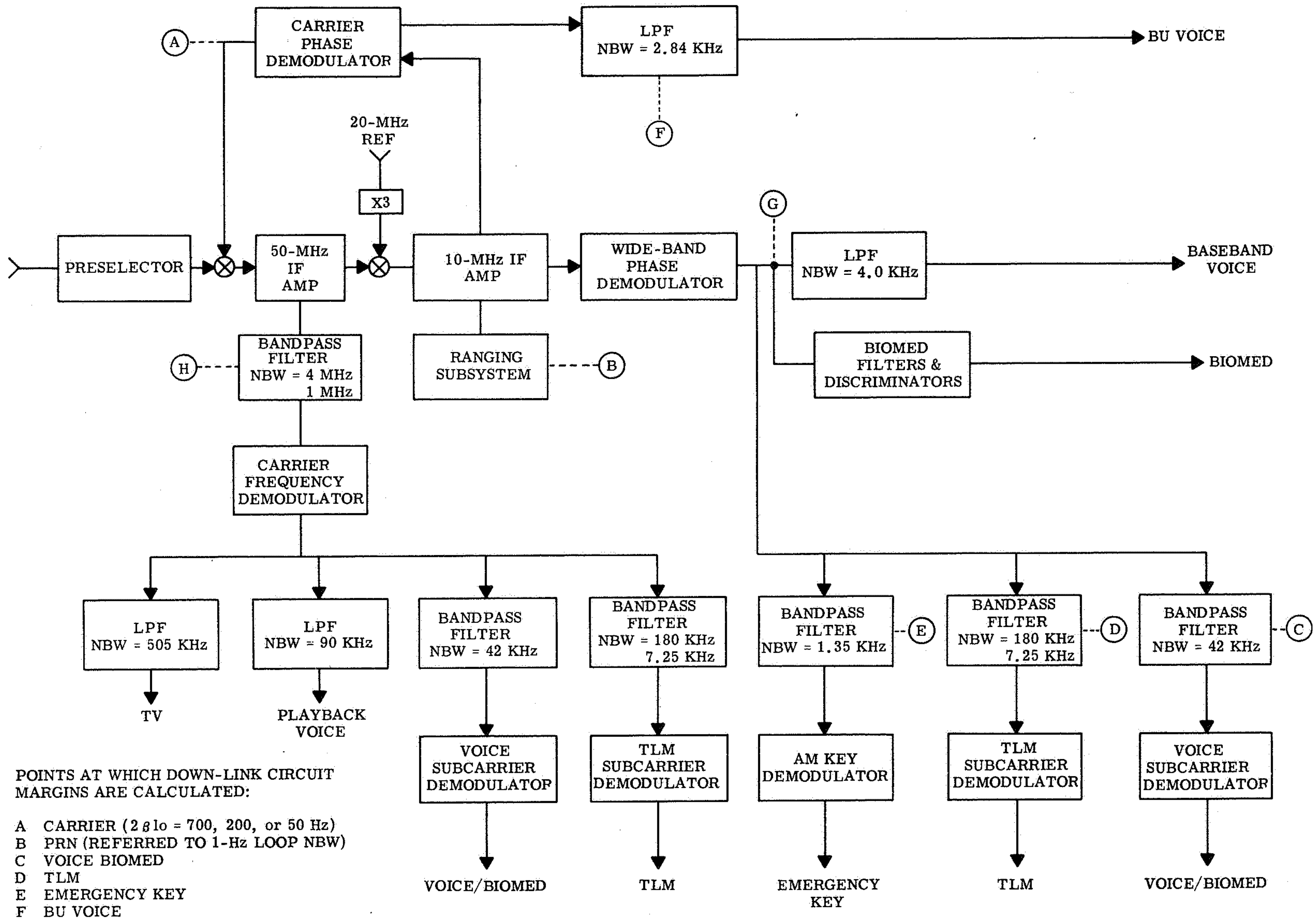
SNR calculations used in this analysis are based on specified values of system parameters. Many of these parameters have estimated "worst" and "best" case tolerances on the specified normal value. All circuit margin calculations used in this report include the "worst" case parameter tolerances; however, in cases where the worst case results are marginal, nominal case margins are calculated to indicate any possible improvement. Appendix A gives a comprehensive listing of the parameter values used for these calculations. Appendix B contains a sample circuit margin calculation for an up-link and down-link channel.

2.2 Circuit Margin Computer Program

The data used to plot circuit margin time histories were generated using the "Apollo Unified S-Band Circuit Margin Program." Tnis program is a computer mechanization of the unified S-band (USB) math model described in reference 1. (Based on work by Bellcomm, JPL, and TRW.)

Figure 2-3 depicts the data flow and sequence of calculations performed when a circuit margin time history is generated. Spacecraft trajectory parameters (SC to MSFN look-angles, slant ranges, etc.) as a function of

*Baseband voice margins are calculated in the postdetection bandwidth.



POINTS AT WHICH DOWN-LINK CIRCUIT MARGINS ARE CALCULATED:

A CARRIER ($2\beta_{lo}$ = 700, 200, or 50 Hz)
B PRN (REFERRED TO 1-Hz LOOP NBW)
C VOICE BIOMED
D TLM
E EMERGENCY KEY
F BU VOICE
G BASEBAND VOICE/BIOMED
H ALL FM CIRCUIT MARGINS

Figure 2-1. Identification of Points At Which Down-Link Circuit Margins Are Calculated In An MSFN Receiver

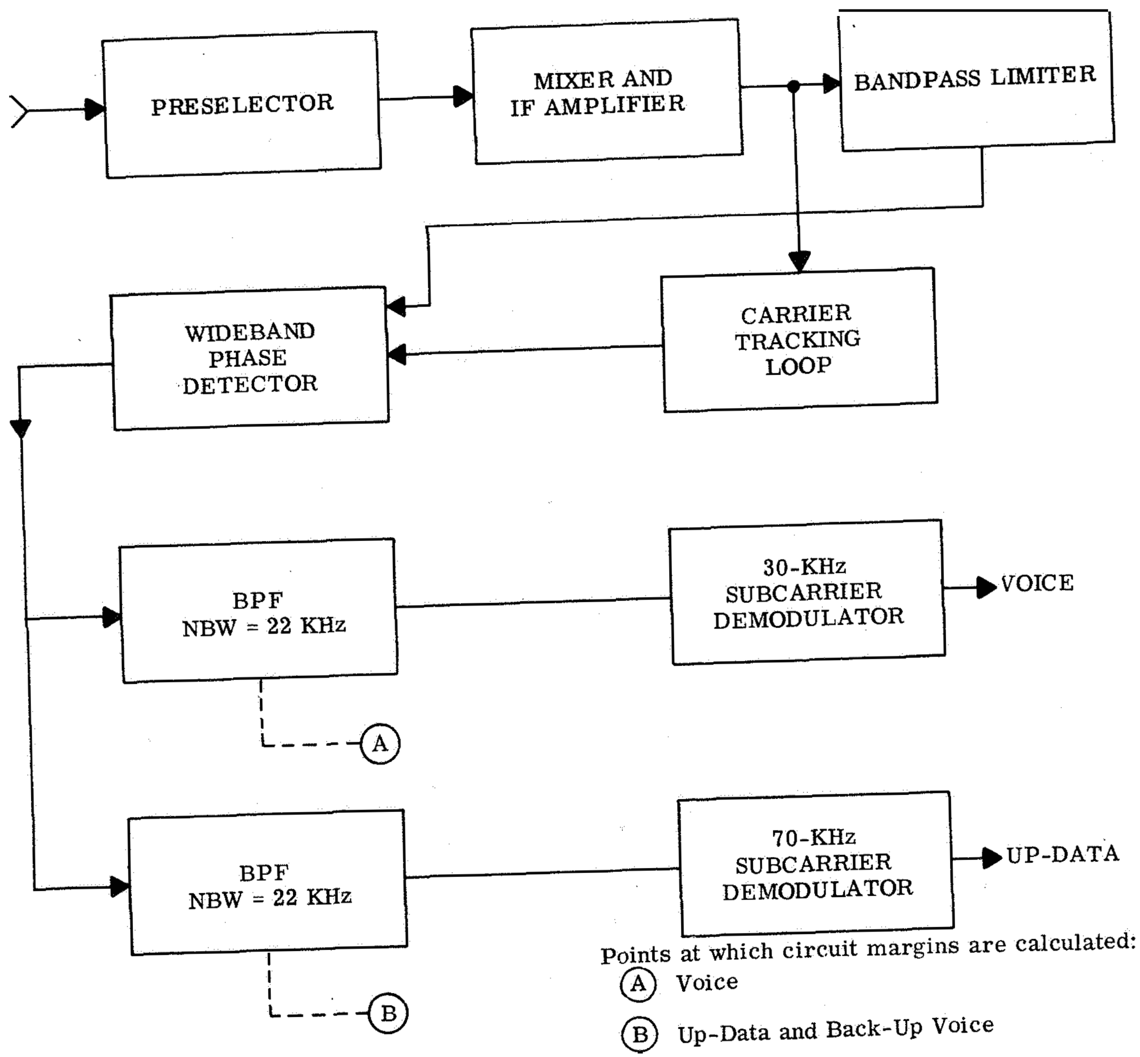


Figure 2-2. Identification of Points At Which Up-Link Circuit Margins Are Calculated In An SC Receiver

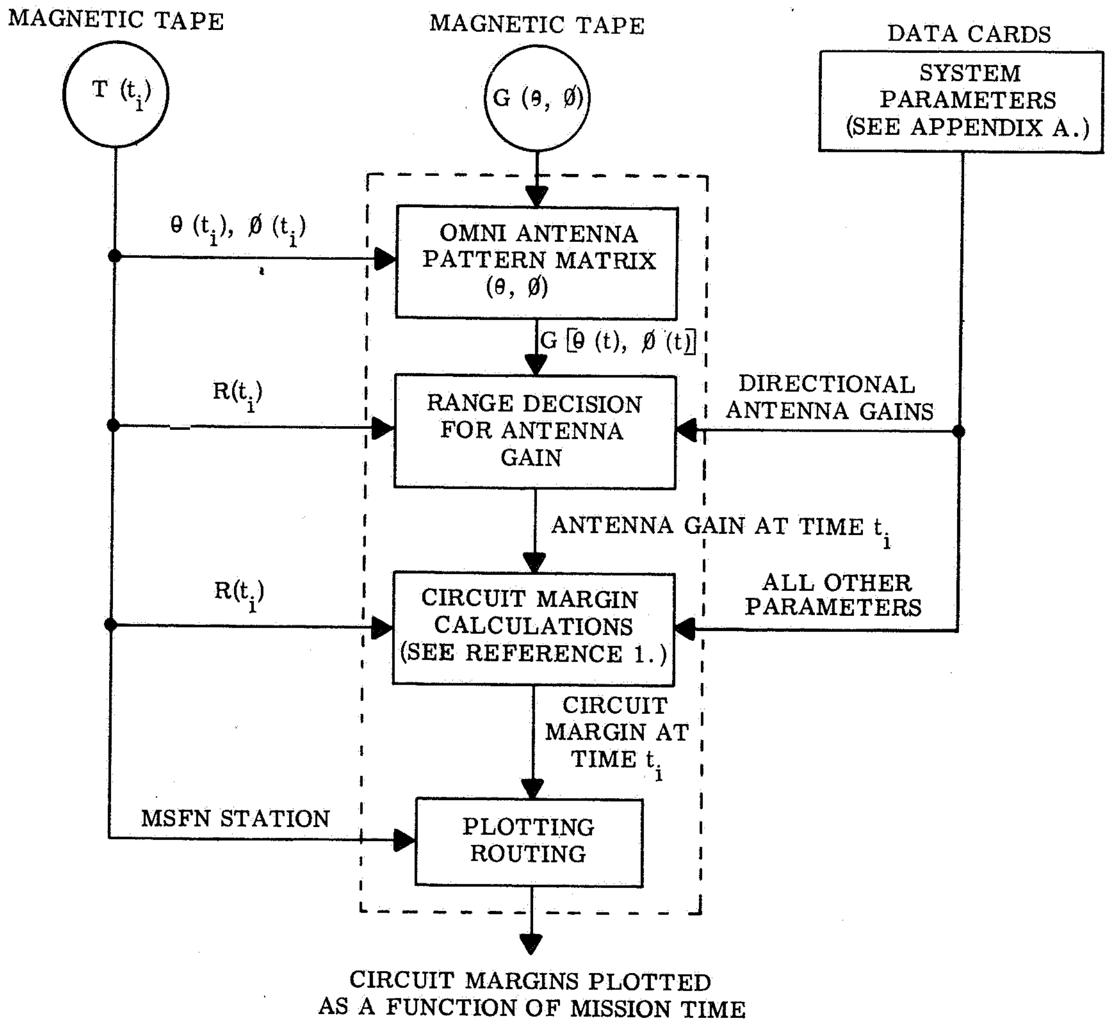


Figure 2-3. Circuit Margin Timeline Data Flow

mission elapsed time, and omni antenna gains as a function of SC to MSFN look-angles, are read into the program from magnetic tape. System parameter values are read in from punched cards. The program utilizes slant range information to determine which antenna to use, based on the criteria in table 2-2. This criteria is based on data taken from the Dalmo Victor Report, "Apollo CSM High Gain Antenna" October 14, 1965, and does not reflect the optimum switching ranges. Based on this report and succeeding data, ISD will define the optimum switching ranges.

TABLE 2-1

REQUIRED PREDETECTION SNR FOR ZERO-DB CIRCUIT MARGINS

Channel	Predetection SNR_{req} (db)	Predetection Noise Bandwidth	Criteria
Normal 51.2Kbps TLM	8.5	180.00 KHz	10^{-6} BER
Normal 1.6Kbps TLM	7.4	7.25 KHz	10^{-6} BER
Back-up 1.6Kbps TLM	3.9	7.25 KHz	10^{-3} BER
Normal Voice/Biomed	8.0	42.00 KHz	90% word intelligibility
*Backup Voice	4.0	2.84 KHz	70% word intelligibility
Baseband Voice	4.0	4.00 KHz	70% word intelligibility
PRN Ranging Code	32.0	1.00 Hz	60 second acquisition
Emergency Key	-10.5	1.35 KHz	20 characters per minute with 60% copying accuracy
FM Playback Voice Playback CSM TLM TV	8.0	4.00 MHz	Carrier frequency demodulator threshold
FM Playback LM Split-Phase TLM	8.0	1.00 MHz	Carrier frequency demodulator threshold
Up-Voice	10.0	22.00 KHz	90% word intelligibility
Up-Data	10.0	22.00 KHz	Maximum message rejection rate of 1 per 1000

*Postdetection Values.

If the omni antenna is selected, SC look-angles determine the antenna gain: If the high-gain antenna is selected, the gain value is obtained from parameter cards. After selecting the slant range and antenna gain, the program calculates a circuit margin for the mode under analysis. The margins are then plotted as a function of mission elapsed time for each station.

TABLE 2-2

PRESET RANGE LIMITS FOR SPACECRAFT ANTENNAS

Antenna	Range
Omni	0 - 2,500 nm
High-Gain WBW	2,500 - 30,000 nm
High-Gain MBW	30,000 - 115,000 nm
High-Gain NBW	115,000 - lunar distance

2.3 Traiectorv Data

The trajectory parameters used in this analysis were taken from a special lunar mission trajectory generated by the Mission Analysis Branch of the Mission Planning and Analysis Division, Manned Spacecraft Center. This trajectory is based primarily on the AS-504 preliminary reference trajectory and is intended only to provide reference data that will be representative of an actual mission. Gimbaling limitations on the high-gain antenna during TLC solar soak maneuvers are not included; thus, use of the high-gain antenna will not be possible for all periods shown in the coverage chart. The launch date selected is February 1, 1968, at 15:35:21 GMT. The lunar landing site is located at latitude 0° 19' 59.8" longitude 24" 49' 59.8". The selected launch azimuth is 72 degrees.

Translunar injection occurs over the Pacific Ocean approximately 3 hours into the mission. The pitch down 41° and attitude hold maneuver begins approximately 3 hr 2 min into the mission, at an altitude of 2400 nautical miles (nm). The maneuver terminates approximately 1 hr 45 min later at an altitude of 18,000 nm. Transposition and docking can occur at any time during this period. Station coverage in this analysis is based on completing the transposition and docking maneuver at an altitude of slightly more than 10,000 nm. The USB stations included are listed in table 2-3, along with the anticipated station capability.

2.4 Omni Antennas

Gain pattern data for the four Block II omni antennas were obtained from full-scale measurements made on the MSC antenna test range by Instrumentation and Electronic Systems Division (IESD). These data will be published by IESD in report form at a future date. The input data to the computer program is a composite of the four antennas, formed by choosing the gain value of the antenna having the highest gain for each set of look-angles. Thus, all predictions using omni antenna gains indicate performance based on optimum switching of the SC antennas. In this respect the omni antenna margins are somewhat optimistic.

TABLE 2-3

MSFN USB GROUND STATIONS

Station	Voice	TLM	Tracking & Ranging	Up-Data	TV	Key	30-Ft. Antenna	85-Ft. Antenna
MILA	X	X	X	X	X		X	
Bermuda	X	X	X	X			X	
Grand Bahama	X	X	X	X			X	
Antigua	X	X	X	X			X	
Ascension	X	X	X	X			X	
Canary Island	X	X	X	X			X	
Madrid	X	X	X	X	X	X		X
Carnarvon	X	X	X	X			X	
Canberra	X	X	X	X	X	X		X
Guam	X	X	X	X			X	
Hawaii	X	X	X	X			X	
Goldstone	X	X	X	X	X	X		X
Guaymas	X	X	X	X			X	
Texas	X	X	X	X			X	

3.0 Down-Link Modes Circuit Margin Analysis

The analysis in this section is divided into two categories: **(1)** down-link modes required during a particular mission phase, but which have negative margins during that phase, and **(2)** specific modes, considered independent of mission requirements, to illustrate the system capability throughout the mission.

3.1 Marginal Modes Performance

Results of this analysis indicate marginal performance at lunar distance for the following down-link modes:

1. CSM PM Mode 8.
2. CSM FM Modes 1, 2, and 4.
3. LM PM Mode 4.

Table **3-1** summarizes the configurations used in circuit margin calculations for these modes.

3.1.1 CSM PM Mode 8 (BU Voice and 1.6Kbps TLM)

CSM PM Mode 8 is a contingency mode designed to provide a voice and TLM link at lunar distance using the SC omni antennas. Figures **3-1** and **3-2** show worst case and nominal case circuit margins at Goldstone during two time segments of the CSM lunar orbit. The periodic loss of signal **(LOS)** and acquisition of signal (AOS), noted on the plots by XXX, is due to occultation of the spacecraft by the moon. Abrupt changes in the plots are due to variations in received RF power caused by differences in SC omni antenna gain as the SC look-angles change.

For the SC attitude profile used here, the margins are negative for a large percentage of the total time in the worst case configuration. Substantial improvement is seen for the nominal case. However, experimental results indicate that TLM channel BER performance may be severely degraded by BU voice interference. A discussion of this degraded TLM performance is given in Appendix D.

3.1.2 CSM FM Modes 1, 2, and 4

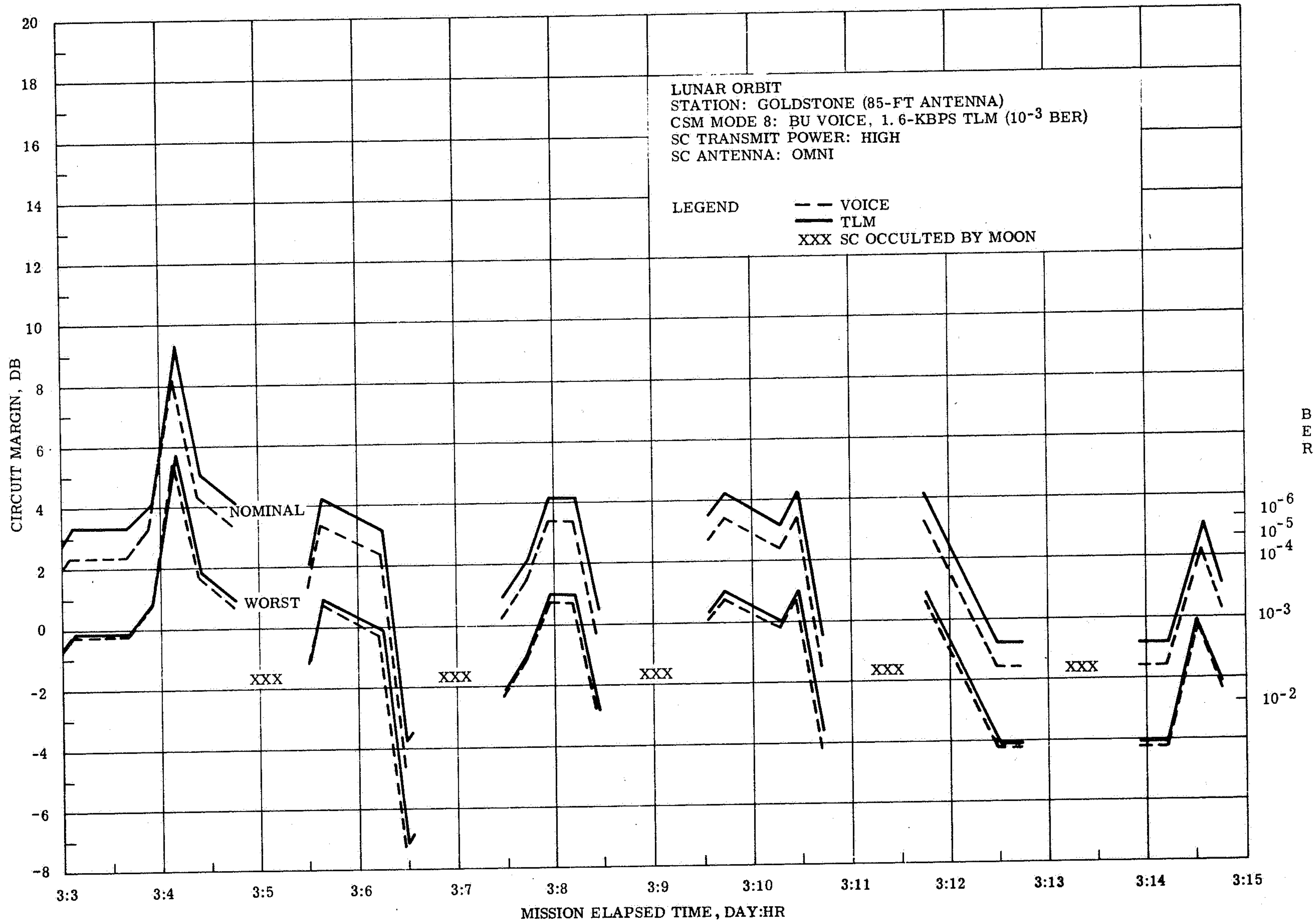
FM Modes 1, 2, and 4 provide 1:1 playback of CSM voice and 51.2Kbps TLM, 32:1 playback of CSM voice and 1.6Kbps TLM, and real-time TV, respectively. The circuit margins presented here are mode-as-a-whole margins rather than margins for the individual channels, i.e., the zero-db circuit margin SNR requirement is based on meeting FM threshold in the carrier frequency demodulator, rather than on meeting a specified output TLM, voice, or TV requirement. Threshold is specified as 8. Odb in the FM predetection bandwidth, which is 4 MHz for Modes 1, 2, and 4, and 1 MHz for Mode 3. The smaller bandwidth results in a positive mode-as-a-whole margin at lunar distance for FM Mode, 3.

TABLE 3-1

MARGINAL MODES AT LUNAR DISTANCE

Mode	Service(s)	Antenna		SC Transmit Power	Criteria
		SC	MSFN		
CSM PM Mode 8	1. 6Kbps TLM BU Voice	Omni	85-foot	High	10^{-3} BER TLM 70% word intelligibility
CSM FM Mode 1	1:1 Playback of: 51. 2Kbps TLM Voice	High-gain NBW	85-foot	High	10^{-6} BER TLM 90% word intelligibility
CSM FM Mode 2	32:1 Playback of: 1. 6Kbps TLM Voice	High-gain NBW	85-foot	High	10^{-6} BER TLM 90% word intelligibility
CSM FM Mode 4	TV	High-gain NBW	85-foot	High	19db output SNR, RMS
LM PM Mode 4	BU Voice 1. 6Kbps TLM	Omni	85-foot	High	70% word intelligibility 10^{-3} BER TLM

Figures 3-3 and 3-4 indicate the nominal and worst case mode-as-a-whole margins for FM Modes 1, 2, and 4 during the translunar coast (TLC) and lunar orbit phases of the mission. The dashed vertical lines, marking abrupt changes in the margin plots, indicate the times at which the SC high-gain antenna beamwidth is switched. The times shown here correspond to preset ranges of 30,000 nm for the wide beamwidth (WBW) to medium beamwidth (MBW) switch, and 115,000 nm for the MBW to narrow beamwidth (NBW) switch. As previously stated in Section 2.2, these are not the optimum switching ranges.



Note: These margins are theoretical and based on the USB math model. Measured data indicates severe degradation of the TLM channel performance due to BU voice interference.

Figure 3-1. CSM Mode 8 Circuit Margin Plot; Nominal and Worst Cases, Lunar Orbit (Third Day)

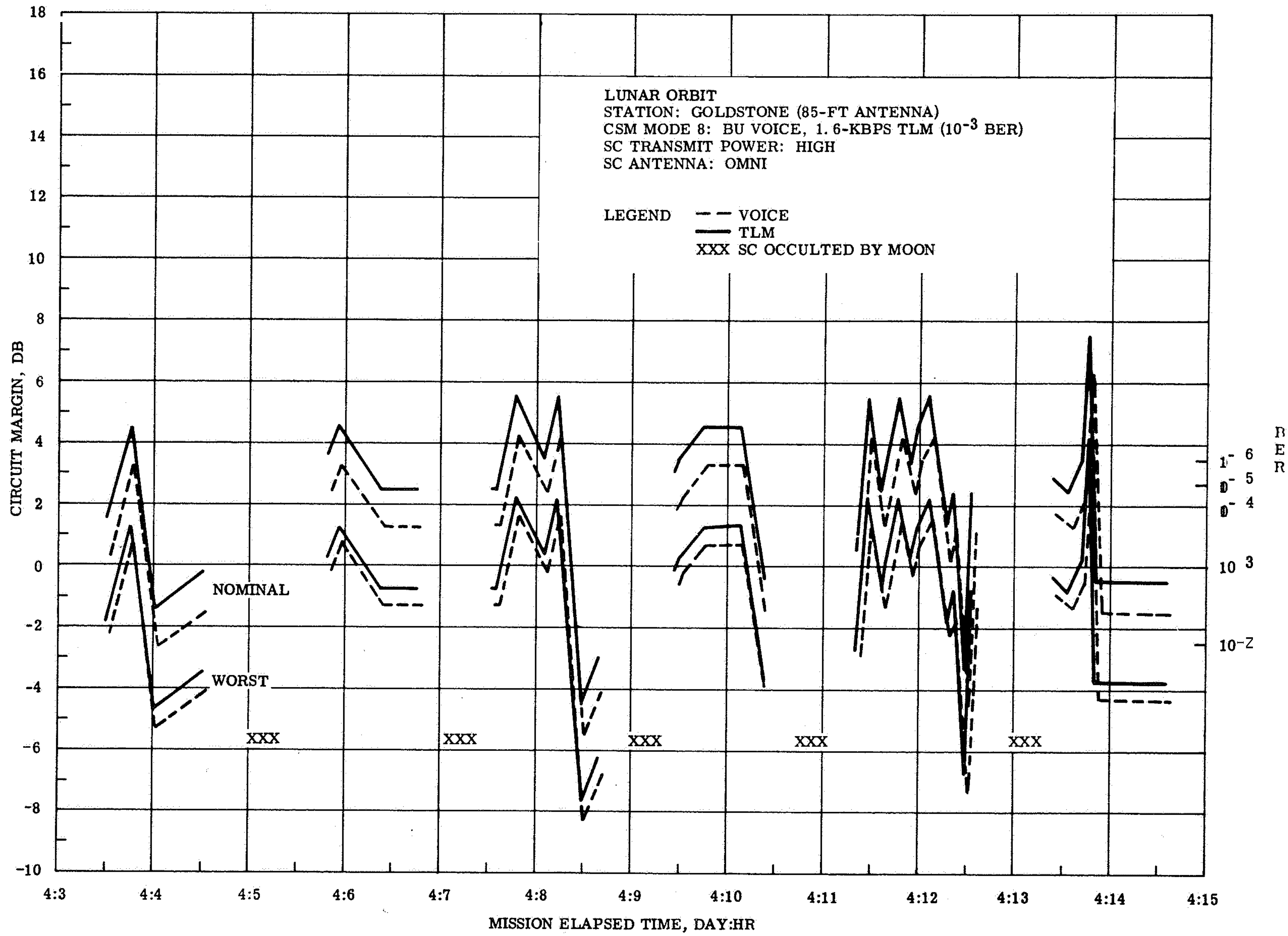
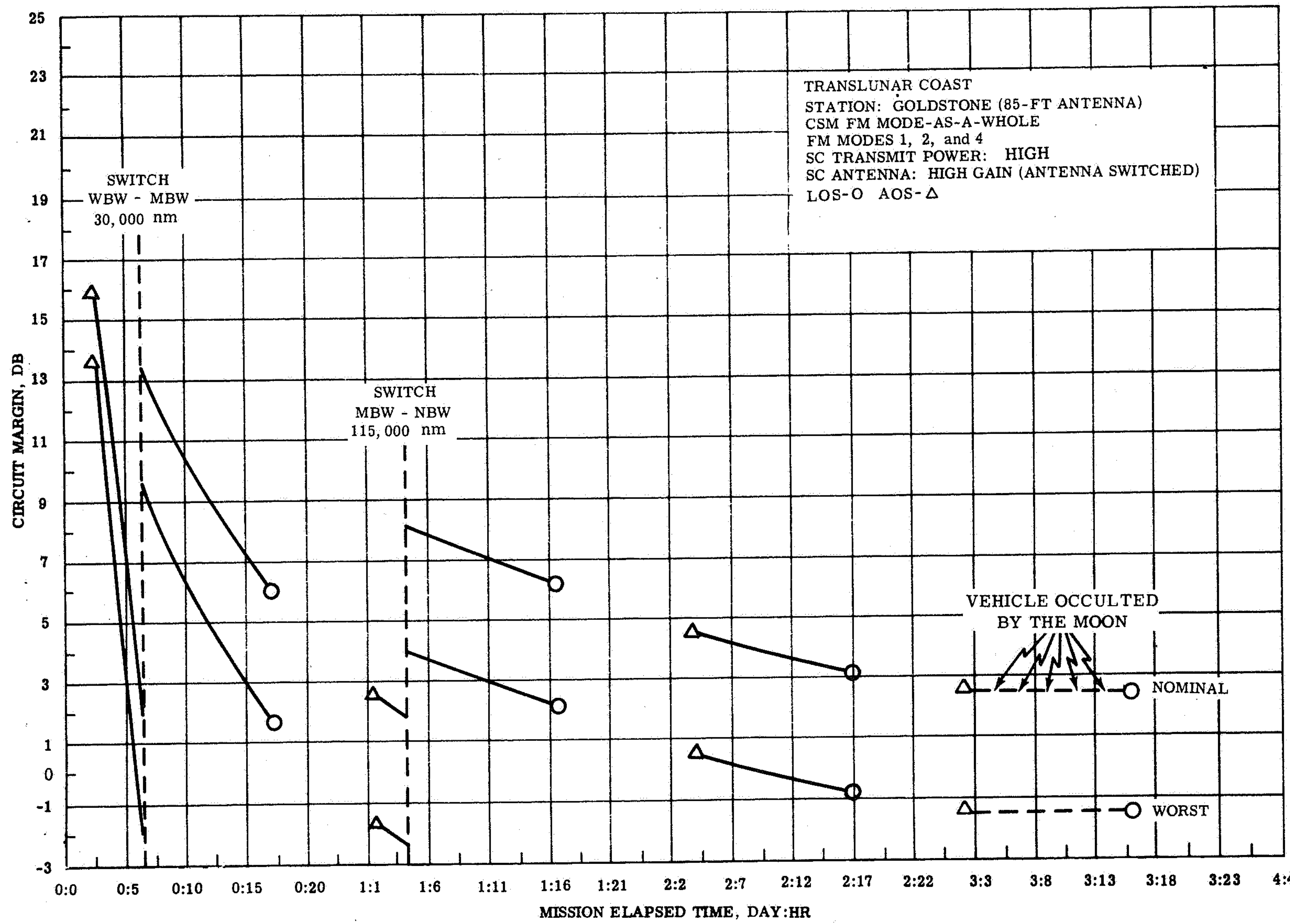


Figure 3-2. CSM Mode 8 Circuit Margin Plot; Nominal and Worst Cases, Lunar Orbit (Fourth Day)



Note: Experimental data indicates that the 8.0db mode-as-a-whole criterion is not adequate for all FM modes. (See Appendix C.)

Figure 3-3. CSM FM Mode-As-A-Whole (Modes 1, 2, and 4) Nominal and Worst Cases, TLC

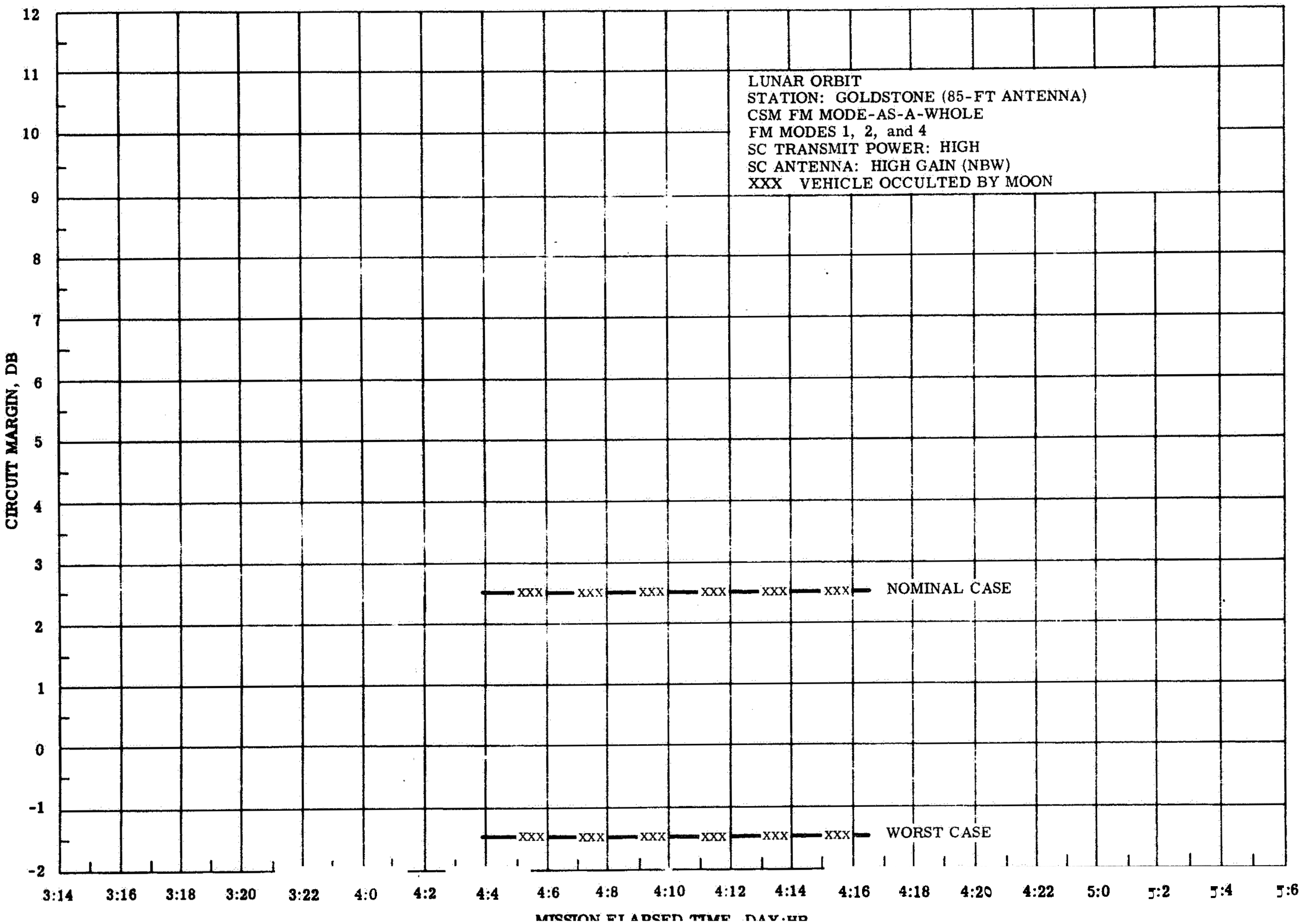


Figure 3-4. CSM FM Mode-As-A-Whole (Modes 1, 2, and 4) Nominal and Worst Cases, Lunar Orbit

The FM margins represent performance predictions based solely on being able to meet threshold requirements of the carrier frequency demodulator. This method of predicting mode performance, although it is specified for the Apollo USB system, is not definitive of the individual channel capability. A discussion of mode-as-a-whole margins as applied to the individual channel performance is given in Appendix C.

3.1.3 LM PM Mode 4 (BU Voice, 1.6Kbps TLM)

LM PM Mode 4 provides voice and 1.6 Kbps TLM at lunar distance using the LM omni antennas. Pattern data for the LM omni antennas were not available when circuit margin timelines were generated for this mission. Therefore, all margins for this mode are based on a nominal -3 db antenna gain.

Figure 3-5 shows the Mode 4 circuit margins for the 85-foot station at Goldstone. It is noted that the margins approach an acceptable level; however, the criteria for calculating these margins are based on achieving minimum usable channel quality (10^{-3} BER and 70-percent word intelligibility).

3.2 Acceptable Modes Performance.

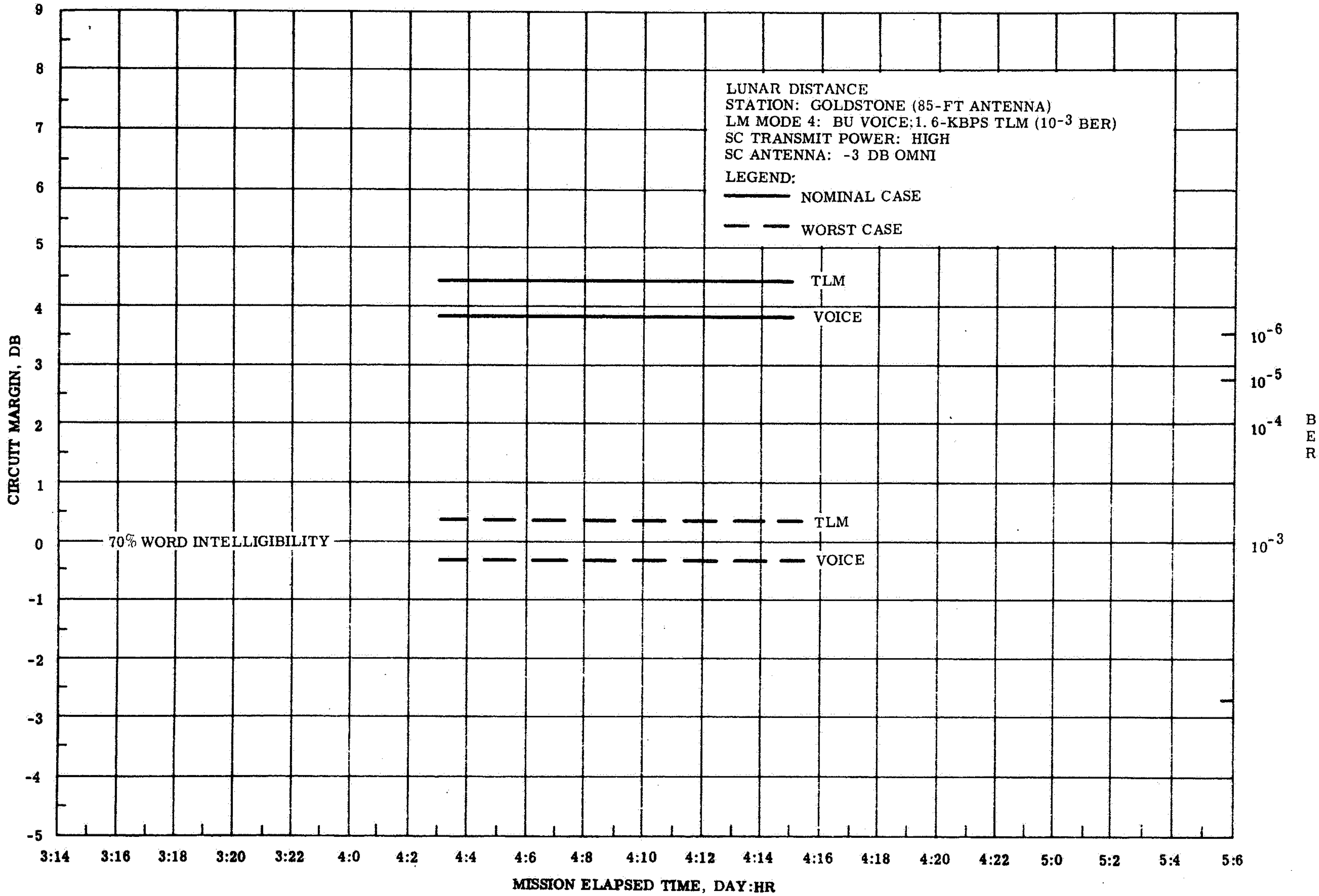
The analysis of this section defines the capability of the USB system to provide satisfactory communication coverage. Circuit margin plots are provided for a 30-foot station and for an 85-foot station for representative modes. In addition, bar graphs define coverage for all stations considered.

The MSFN stations considered are those specified in the typical lunar mission trajectory and listed in table 2-3. Ship and aircraft locations are not specified in the trajectory and are therefore not included in the analysis.

The bar graphs depicting station coverage are pattern coded to indicate the spacecraft antenna that must be used to provide positive margins during the time indicated. A mean value of slant range, corresponding to mission time, is indicated at the top of each chart. These ranges can be used to approximate the maximum slant range to which a particular SC antenna can be used with a given operational mode.

The periods when a vehicle is occulted by the moon are bounded by the times when simultaneous loss and simultaneous acquisition of coverage are indicated for all stations with line-of-sight to the spacecraft.

The circuit margin plots provided are for the MSFN stations at Goldstone and MILA. These plots are representative of the margins observed at other 85-foot stations and at 30-foot stations with uncooled paramps.



Note: These margins are theoretical and based on the USB math model. Measured data indicates severe degradation of the TLM channel performance due to BU voice interference.

Figure 3-5. LM Mode 4 Circuit Margin Plot; Nominal and Worst Cases

Thirty foot stations with cooled paramps have approximately an additional 2 db margin. On these plots, as on those in Section 3.1, the dashed vertical lines indicate the times at which the SC high-gain antenna is switched from WBW to MBW or from MBW to NBW. Here again, switching occurs at 30,000 and 115,000 nm, and does not indicate the maximum usable range of the antenna.

3.2.1 CSM PM Normal Modes (Modes 1, 2, 3, and 4)

CSM PM modes 1, 2, 3, and 4 are referred to as the normal CSM modes. These modes provide the maximum number of information channels, and are designed to operate at lunar distance only when the SC high-gain antenna and high-power transmitting configuration is operable. Table 3-2 lists the services provided by each of these modes and summarizes the equipment configurations used to calculate the circuit margins presented in this section.

Only CSM PM Modes 1, 2, and 3 are considered. Since the margins for Mode 3 (Mode 4 plus PRN ranging) are positive for all mission phases, plotting of Mode 4 would be redundant. Based on the trajectory for this mission, communications in Modes 3 or 4 are both satisfactory.

TABLE 3-2

CSM PM NORMAL DOWN-LINK MODES AND ANT INNA/POWER CONFIGURATIONS

Mode	Service(s)	Antenna		Transmit Power		Criteria
		SC	MSFN	SC	MSFN	
CSM PM Mode 1	51.2Kbps TLM Voice	Omni High-gain	30-foot 85-foot	High	N/A	10^{-6} BER, 90% word intelligibility
CSMPM Mode 2	PRN 51.2Kbps TLM Voice	Omni High-gain	30-foot 85-foot	High Low	High	60-sec. acquisition time, 90% word intelligibility 10^{-6} BER TLM
CSMPM Mode 3	PRN 1.6Kbps TLM Voice	Omni High-gain	30-foot 85-foot	High Low	High	60-sec. acquisition time, 90% word intelligibility 10^{-6} BER TLM
CSM PM Mode 4	1.6Kbps TLM Voice	NOT PLOTTED				

Circuit margins for the CSM PM Mode 1 information channels are plotted in Figures 3-6 and 3-7. Since the margins are good at lunar distance with a 30-foot station, only the plots for MILA are included. Figures 3-8 and 3-9 show the station coverage for Mode 1 from TLI through transearth injection (TEI).

Two SC power configurations are included for CSM PM Mode 2. Figures 3-10 and 3-11 are plots of the Mode 2 margins at Goldstone using the SC low-power (2.8 watts) mode. Figures 3-12 and 3-13 are the station coverage charts for Mode 2 using low power. Note that at lunar distance, only the 85-foot stations provide communication.

Lunar distance circuit margins for Mode 2 using the SC high-power mode and the 30-foot station at MILA are shown in figure 3-14. Station coverage charts for Mode 2, high power, are figures 3-15 and 3-16. Note that coverage is the same as for Mode 1.

CSM PM Mode 3 circuit margins are plotted for the 30-foot station at MILA in figures 3-17 and 3-18. These margins are for the SC low-power mode. The coverage charts for Mode 3, in figures 3-19 and 3-20 are based on the SC high-power output. The point to note in Figure 3-20 is if the NBW antenna is inoperable, the SC high power mode must be used. However, since the margins shown in Figure 3-18 are positive, use of the NBW antenna eliminates the need to operate in the high power mode.

3.2.2 CSM PM Contingency Modes (Modes 5, 6, 7, 9, and 10)

The CSM PM contingency modes provide communications when the omni antenna and/or the SC by-pass power output are used. These modes, the services provided, and the equipment configurations used in the circuit margin calculations are listed in table 3-3. Only modes 5, 6, and 10 are considered here. Mode 8 is marginal and is discussed in section 3.1.1. Modes 7 and 9 are backup PRN modes and have positive margins only if the up-link is limited to PRN ranging information.

Figures 3-21 through 3-26 are based on omni antenna gains, which vary with SC look-angles. The abrupt changes noted in the margin plots are caused by this variation in antenna gain. Time periods when the vehicle is occulted by the moon are noted on the plots.

Figure 3-21 shows Mode 5 TLM circuit margins for both the nominal and worst cases. For the worst case, the margins are negative for only a small percentage of time. Thus, the probability of achieving adequate performance in this channel is good. Figure 3-22 shows the station coverage for Mode 5 based on nominal tolerance calculations.

TABLE 3-3

CSM PM CONTINGENCY MODES AND ANTENNA/POWER CONFIGURATIONS

Mode	Service(s)	Antenna SC	Antenna MSFN	Transmitter Power SC	Transmitter Power MSFN	Criteria
CSM PM Mode 5	1.6Kbps TLM	Omni	85-foot	High	High	10^{-3} BER
CSM PM Mode 6	Emergency Key	Omni	85-foot	By-Pass	High	20 characters/ min. at 60% copying accuracy
CSM PM Mode 7	PRN	Not Plotted				
CSMPM Mode 8	1.6Kbps BU Voice	See Section 3.1.1				
CSMPM Mode 9	PRN 1.6Kbps TLM	Not Plotted				
CSM PM Mode 10	BU Voice	Omni	85-foot 30-foot	High	High	70%word intelligi- bility

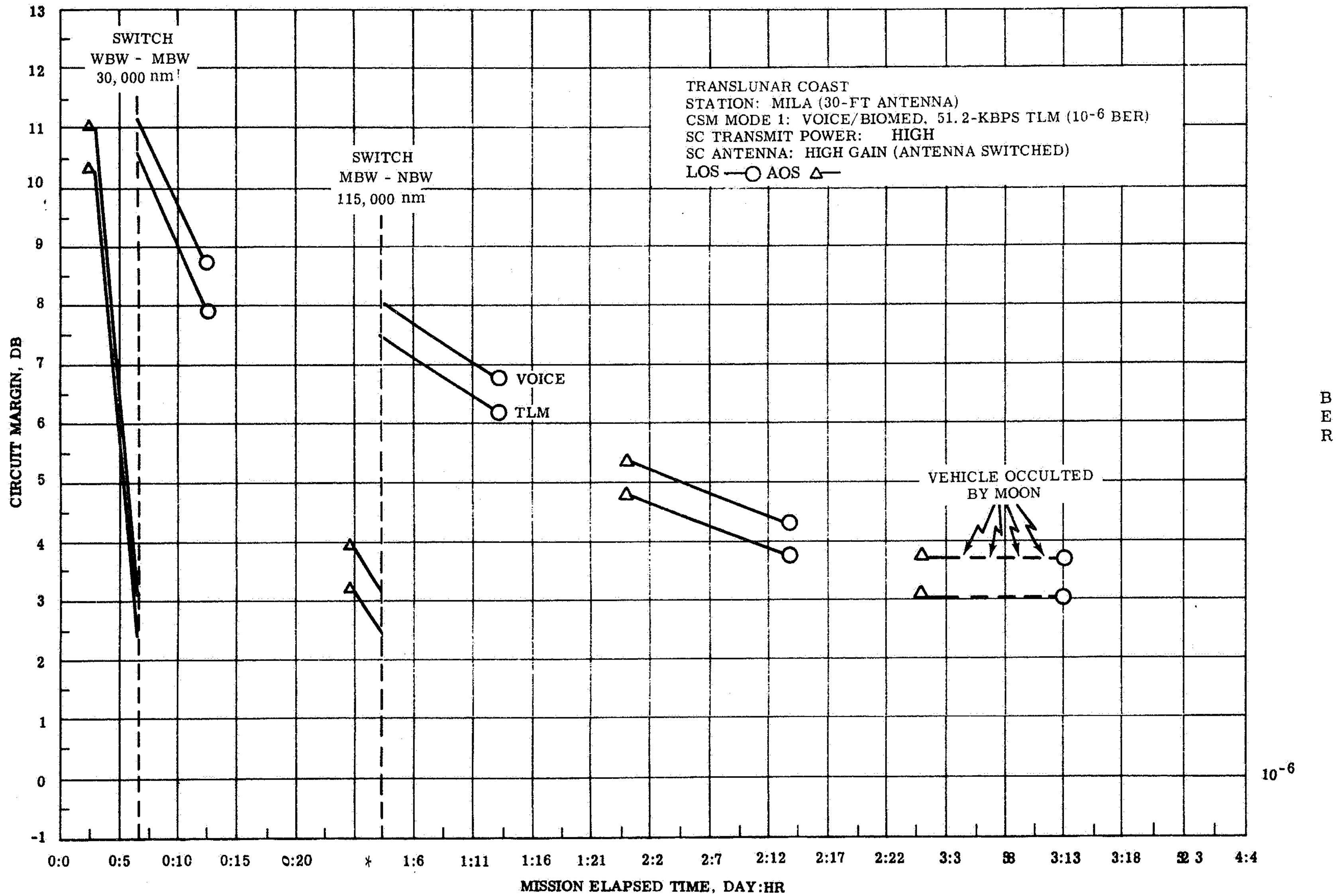


Figure 3-6. CSM Mode 1 Circuit Margin Plot; Worst Case, ⊓LC

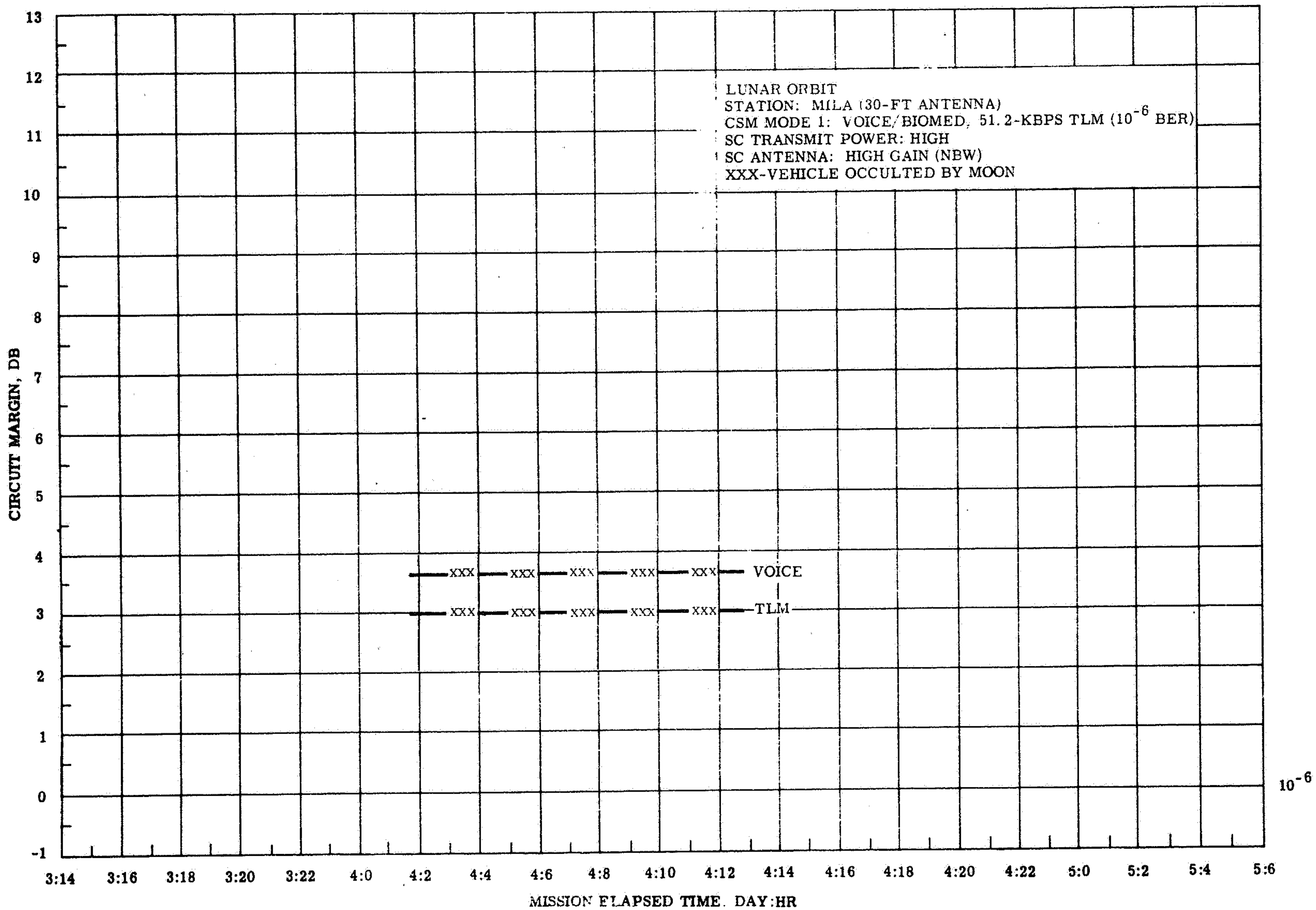


Figure 3-7. CSM Mode 1 Circuit Margin Plot; Worst Case, Lunar Orbit

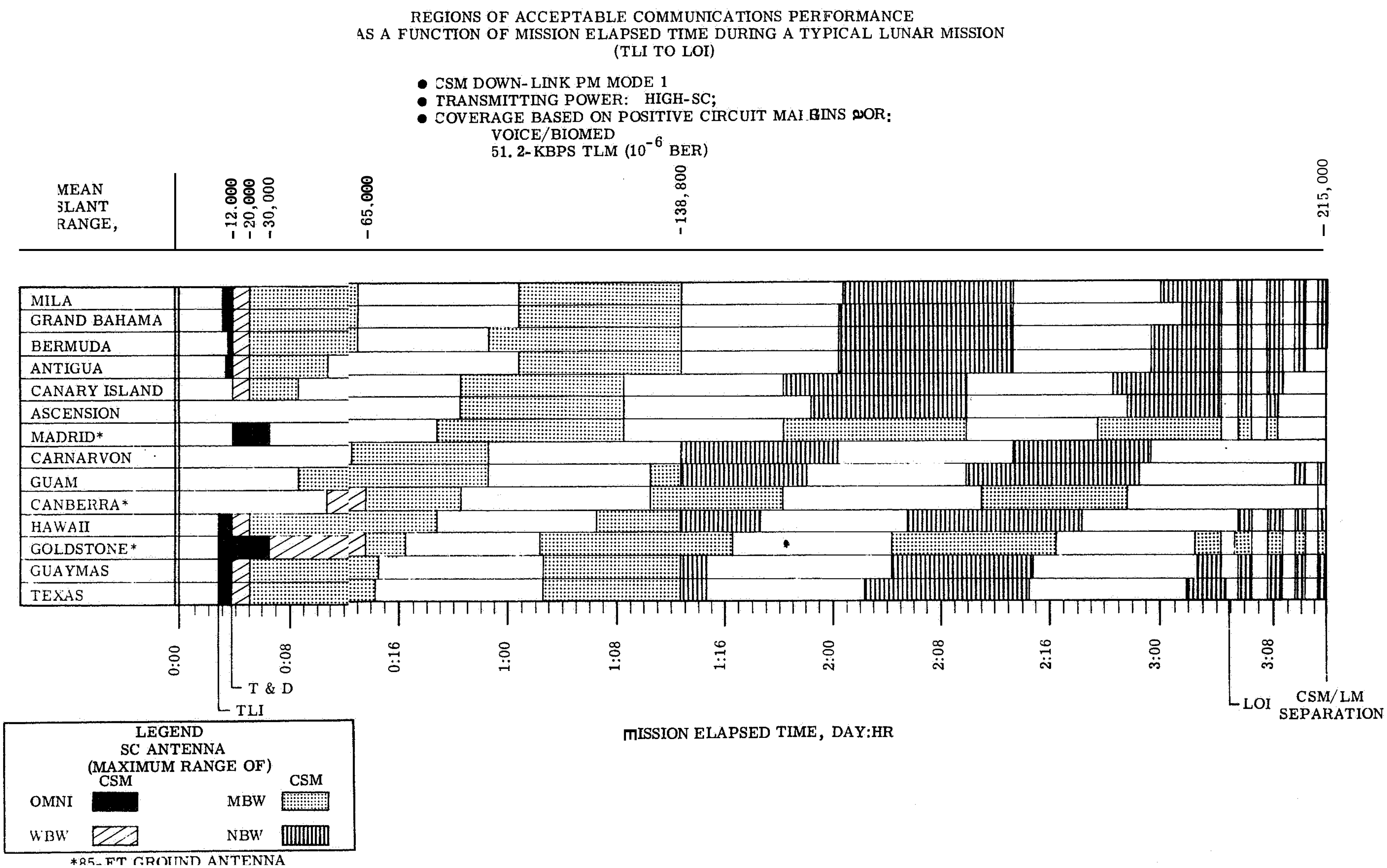


Figure 3-8. CSM Mode 1 Station Coverage; Worst Case, TLC

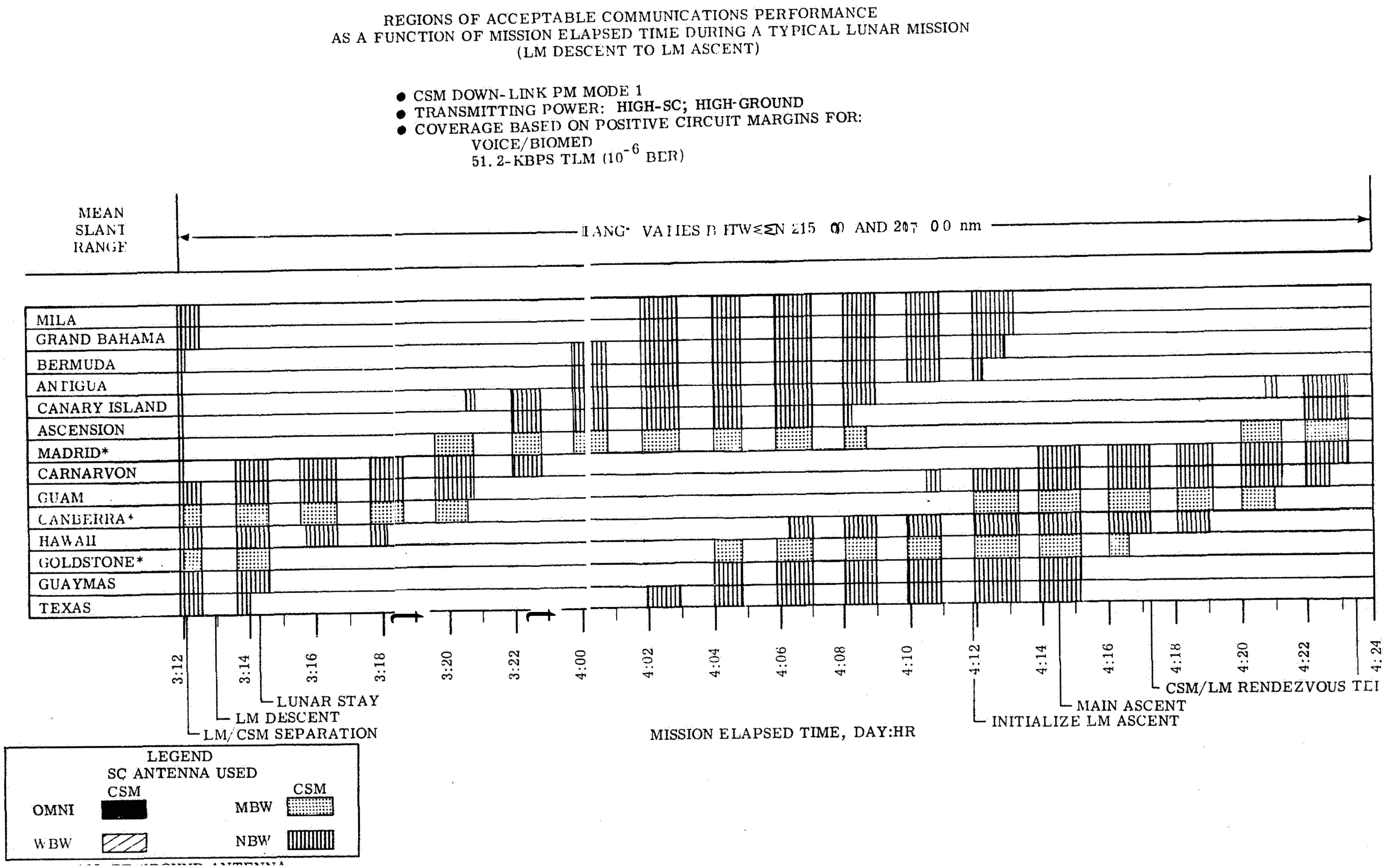


Figure 3-9. CSM Mode 1 Station Coverage; Worst Case, Lunar Orbit

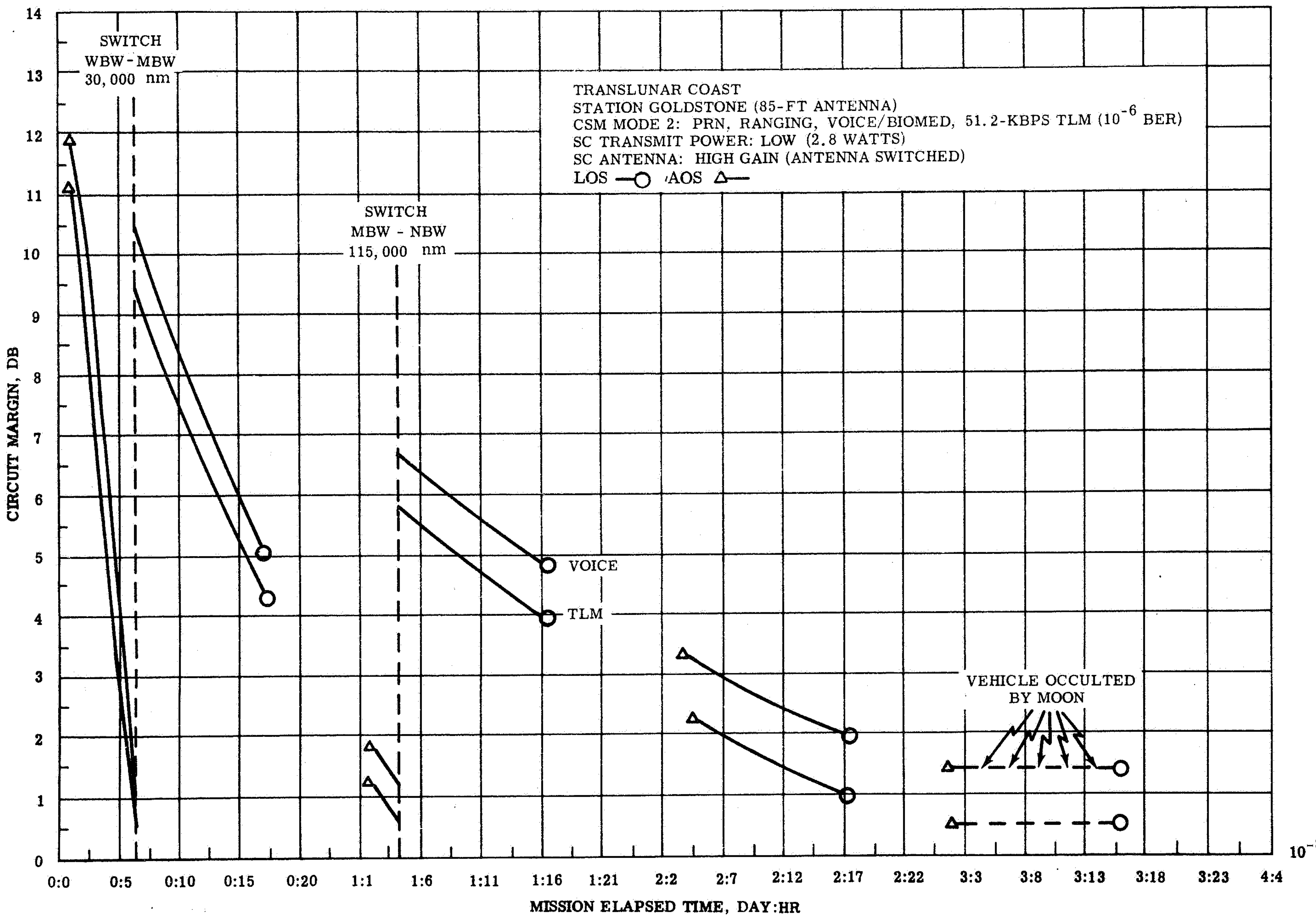


Figure 3-10. CSM Mode 2 Circuit Margin Plot; Worst Case, TLC

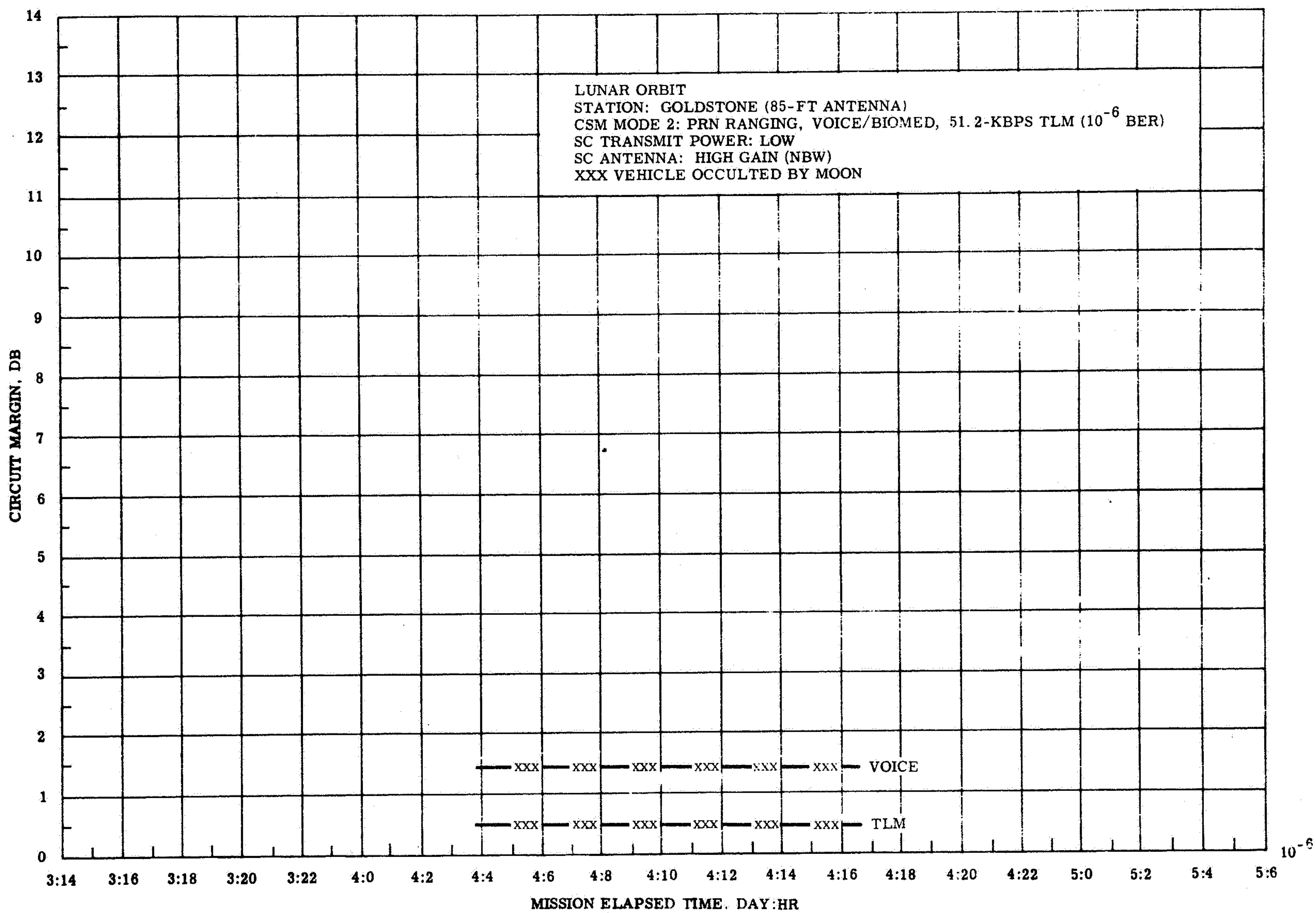


Figure 3-11. CSM Mode 2 Circuit Margin Plot; Worst Case, Lunar Orbit

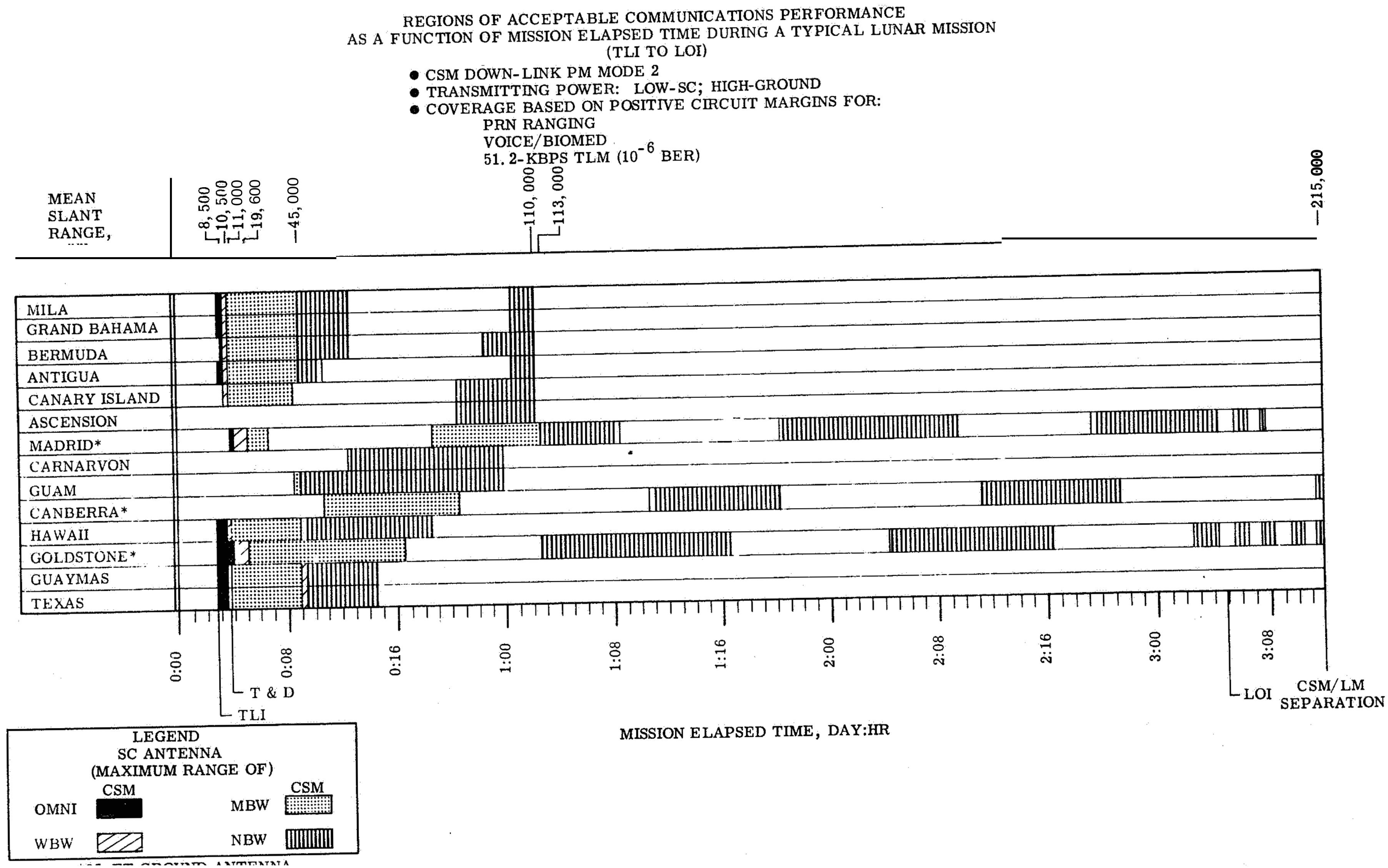


Figure 3-12. CSM Mode 2 Station Coverage; Worst Case, TLC

REGIONS OF ACCEPTABLE COMMUNICATIONS PERFORMANCE
AS A FUNCTION OF MISSION ELAPSED TIME DURING A TYPICAL LUNAR MISSION
(LM DESCENT TO LM ASCENT)

- CSM DOWN-LINK PM MODE 2
- TRANSMITTING POWER: LOW-SC; HIGH-GROUND
- COVERAGE BASED ON POSITIVE CIRCUIT MARGINS FOR:
  - 51.2-KBPS TLM (10^{-6} BER)
  - VOICE (90% INTELLIGIBILITY)
  - PRN

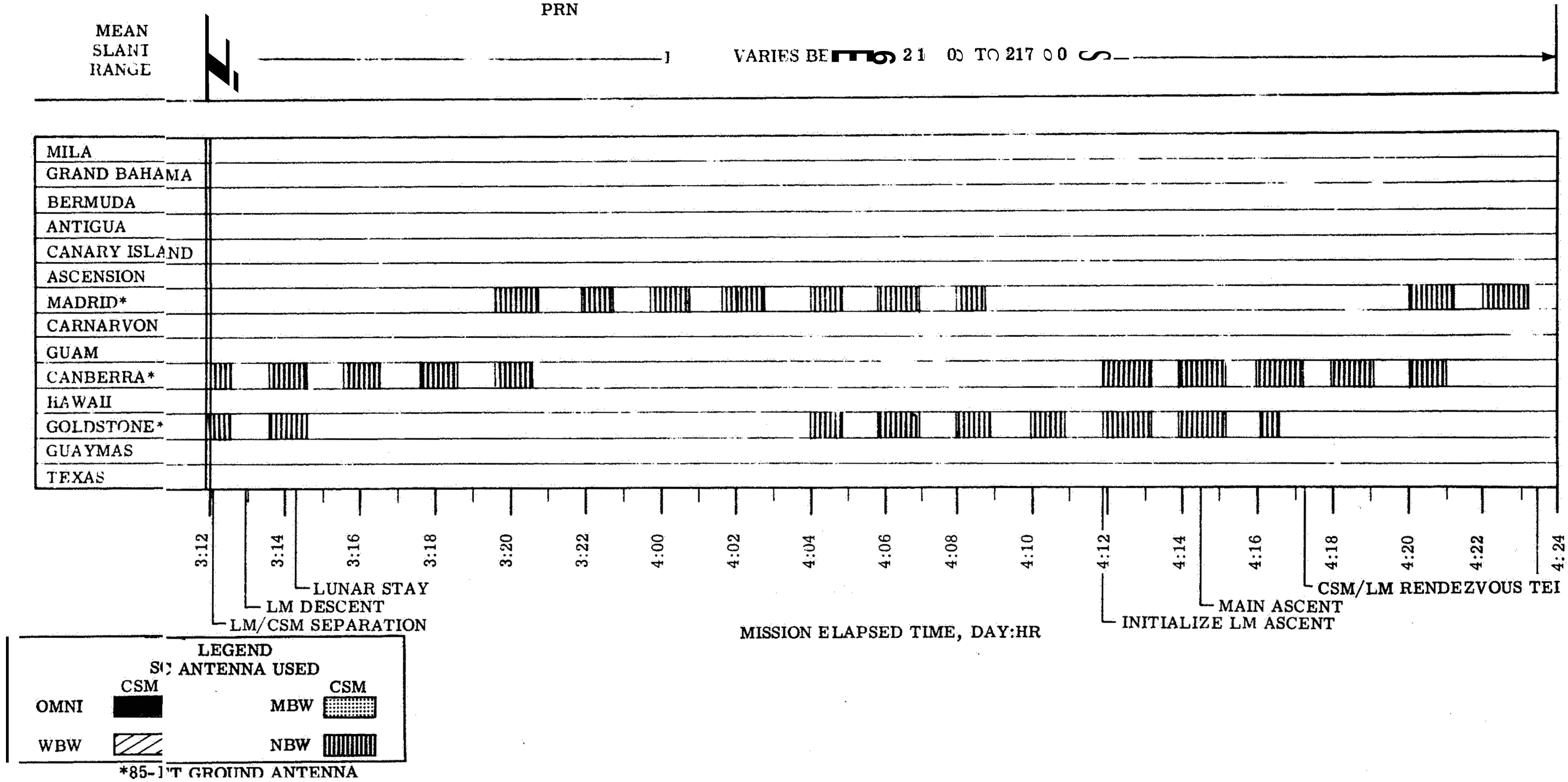


Figure 3-13. CSM Mode 2 Station Coverage Worst Case, Lunar Orbit

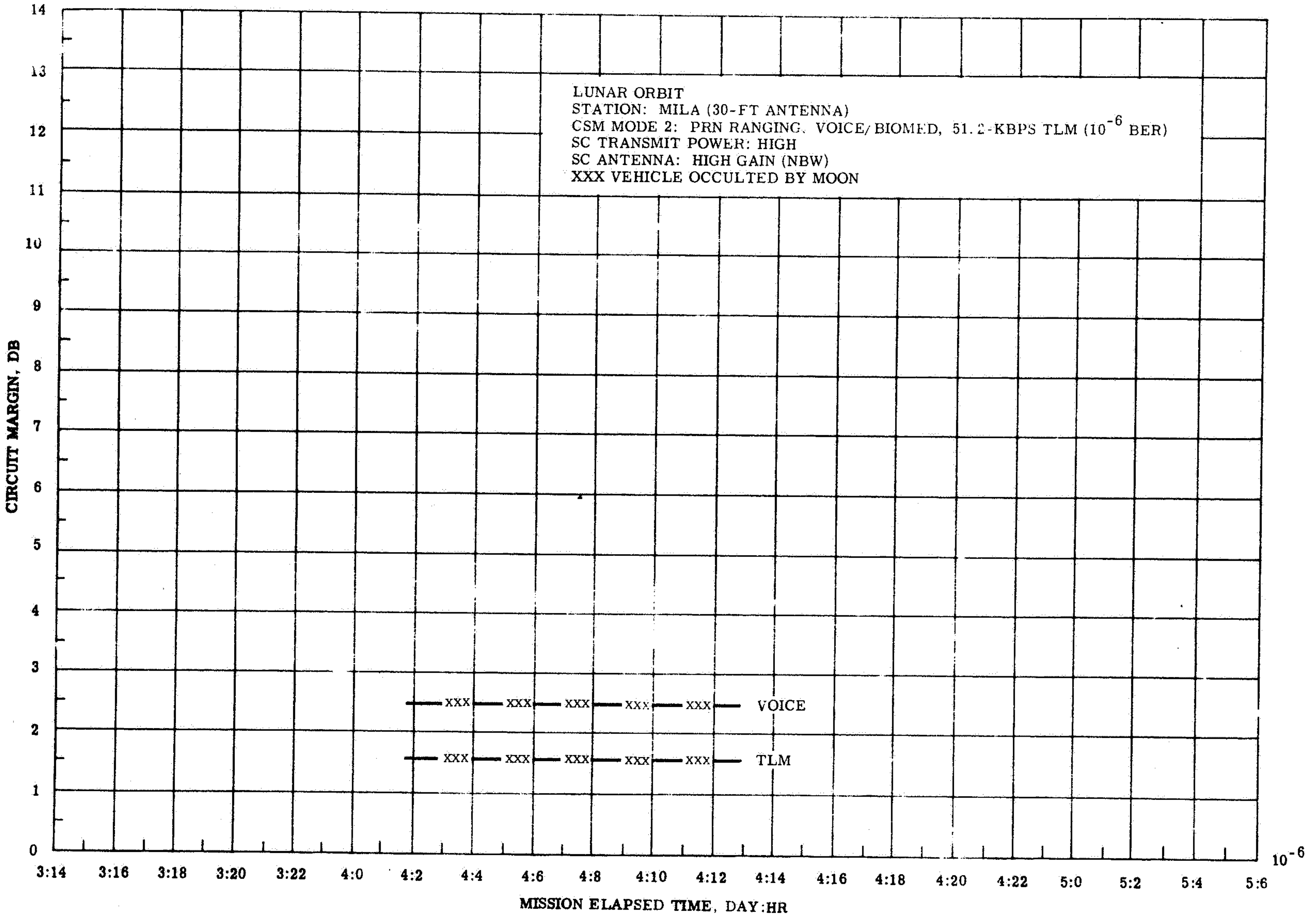


Figure 3-14. CSM Mode 2 Circuit Margin Plot, Worst Case, Lunar Orbit

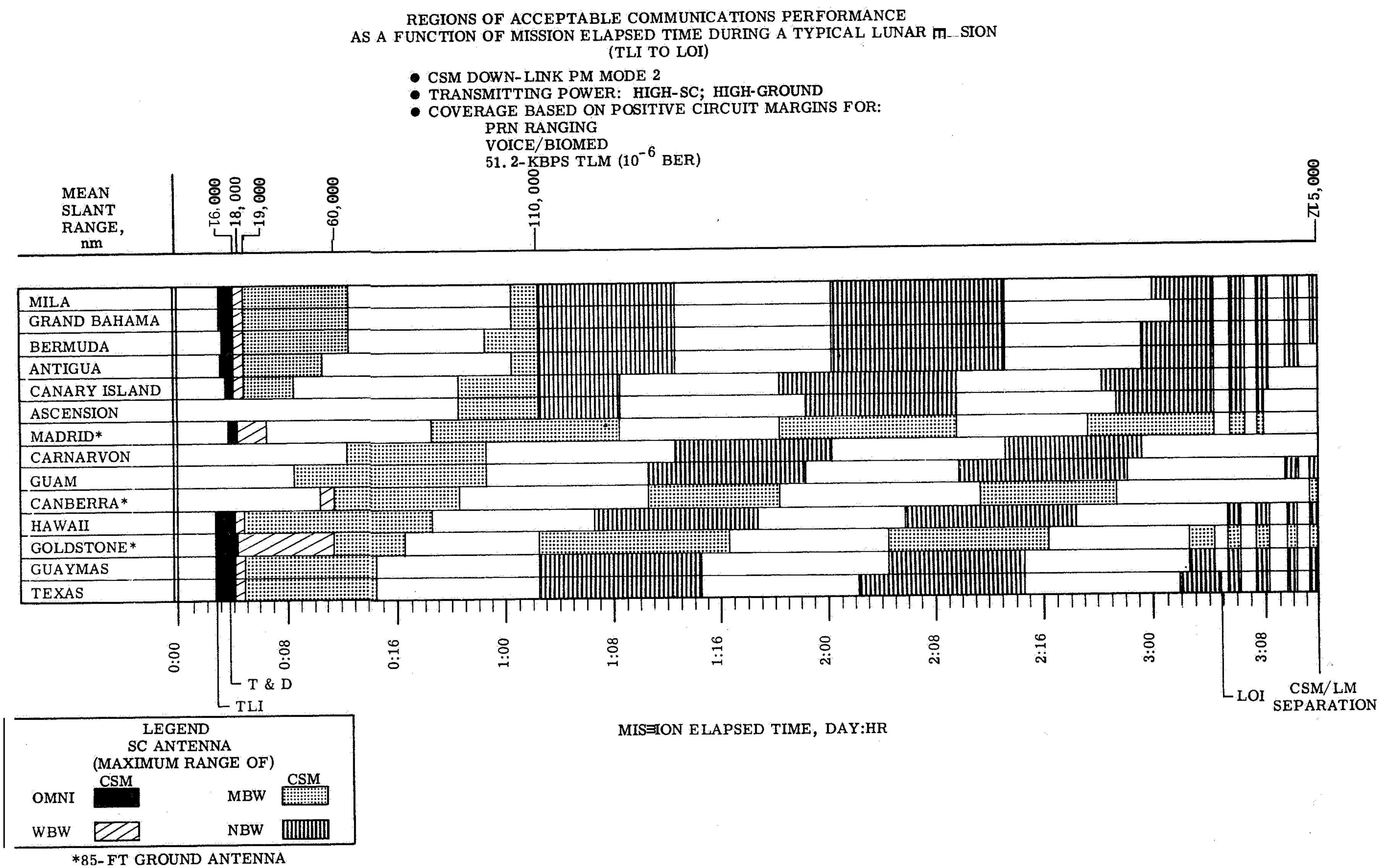


Figure 3-15. CSM Mode 2 Station Coverage; Worst Case MLC

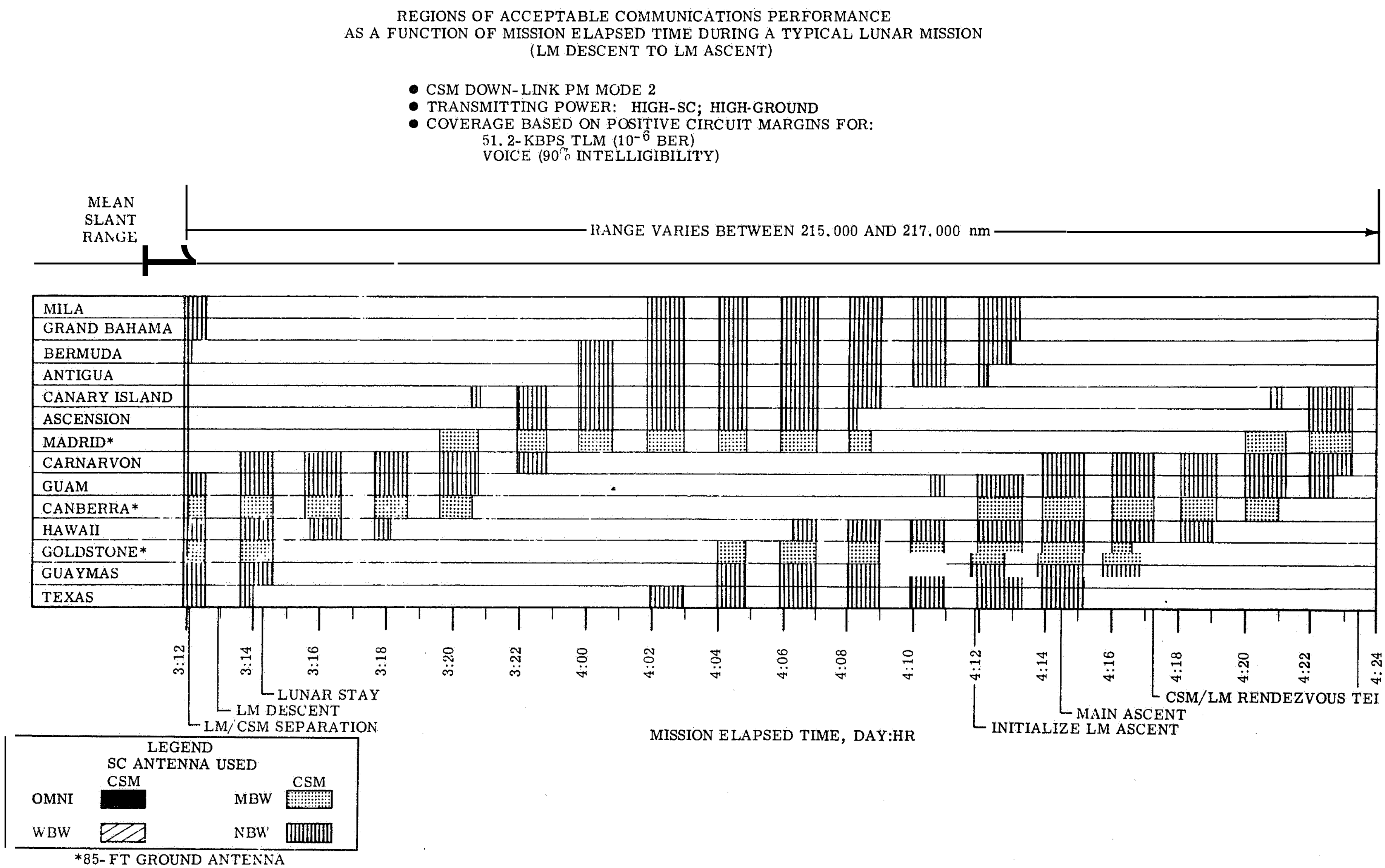


Figure 3-16. CSM Mode 2 Station Coverage; Lunar Orbit

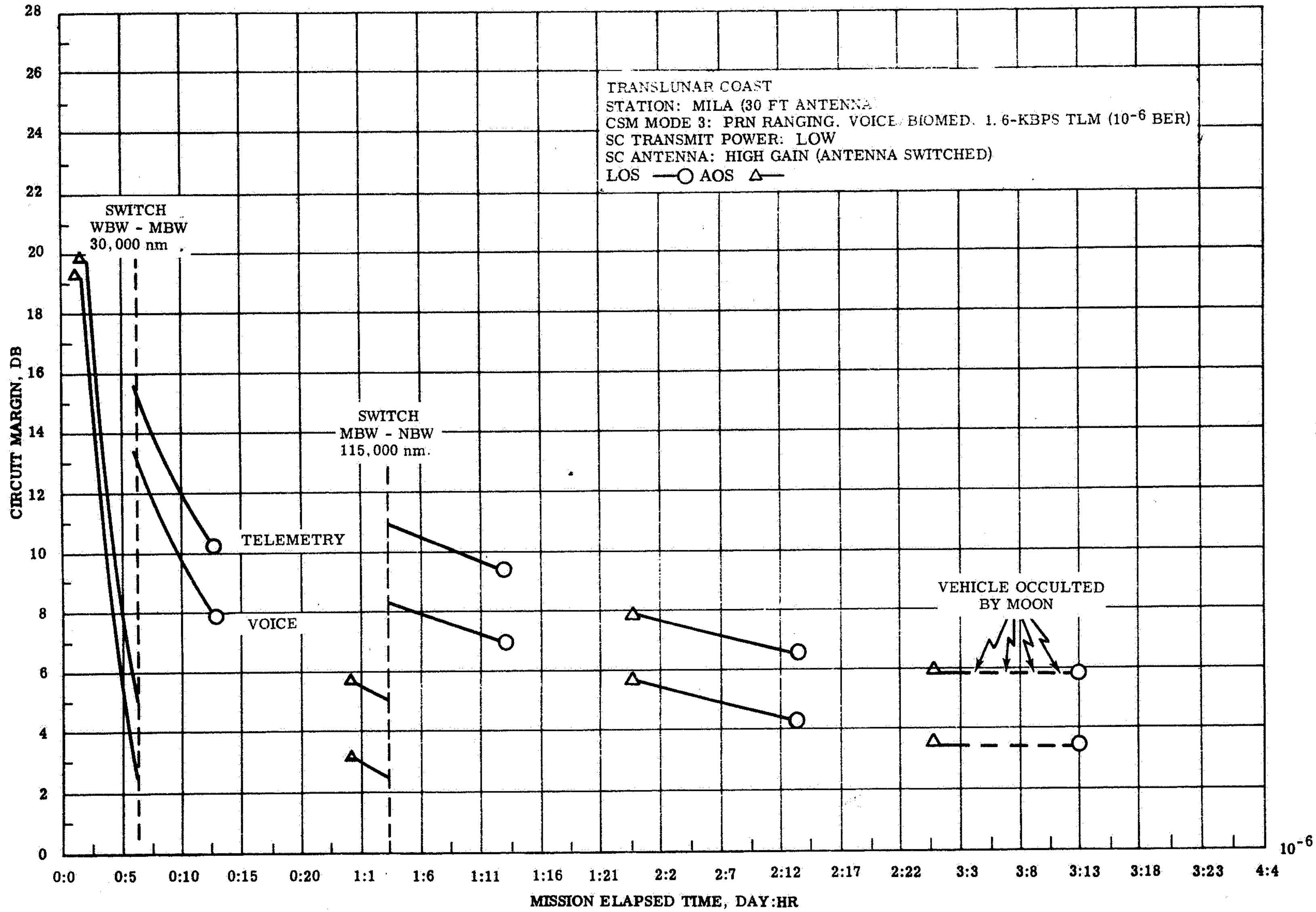


Figure 3-17. CSM Mode 3 Circuit Margin Plot; Worst Ca≡e, TLC

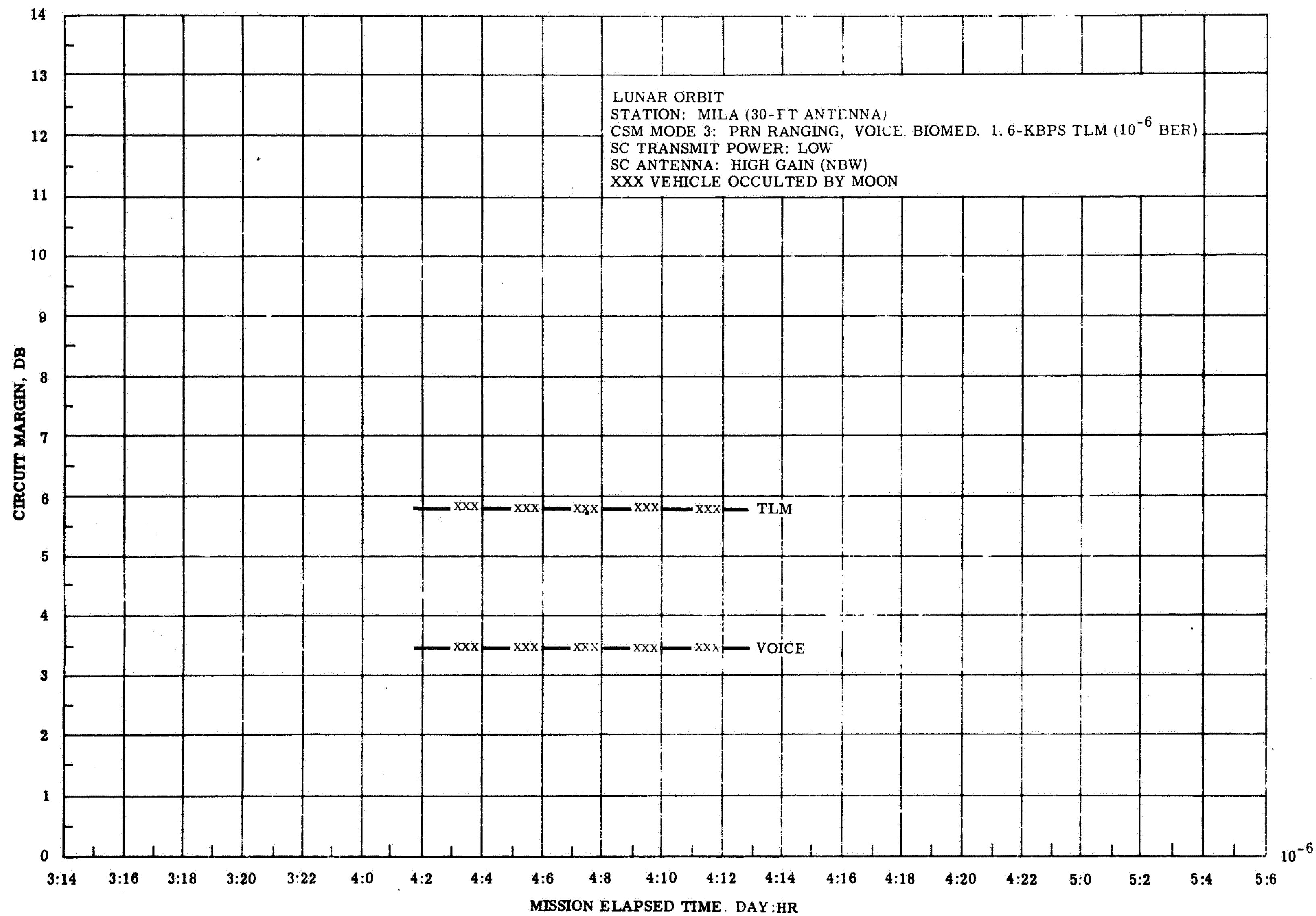


Figure 3-18. CSM Mode 3 Circuit Margin Plot; Worst Case, Lunar Orbit

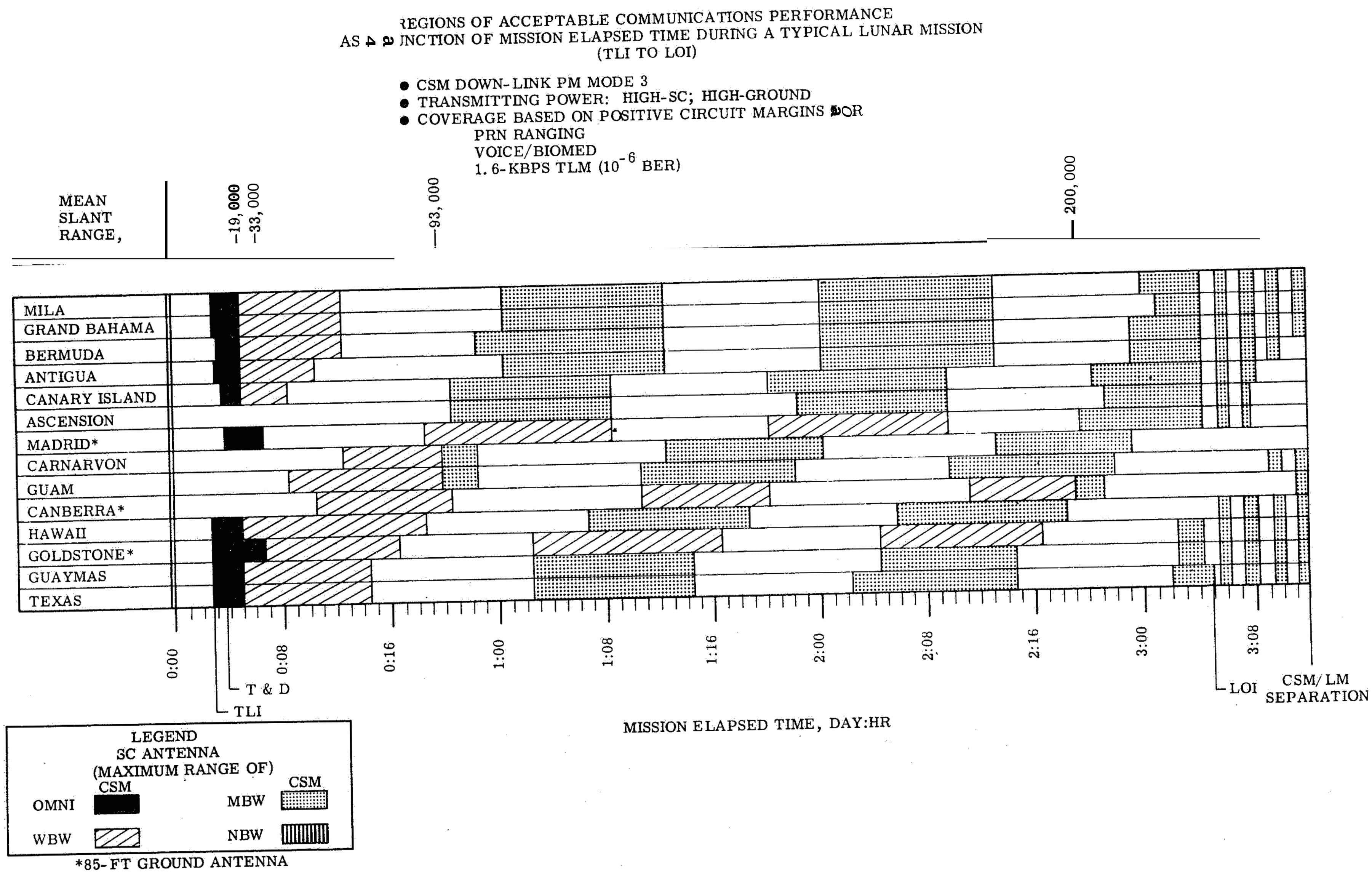


Figure 3-19. CSM Mode 3 Station Coverage; Worst Case, MLC

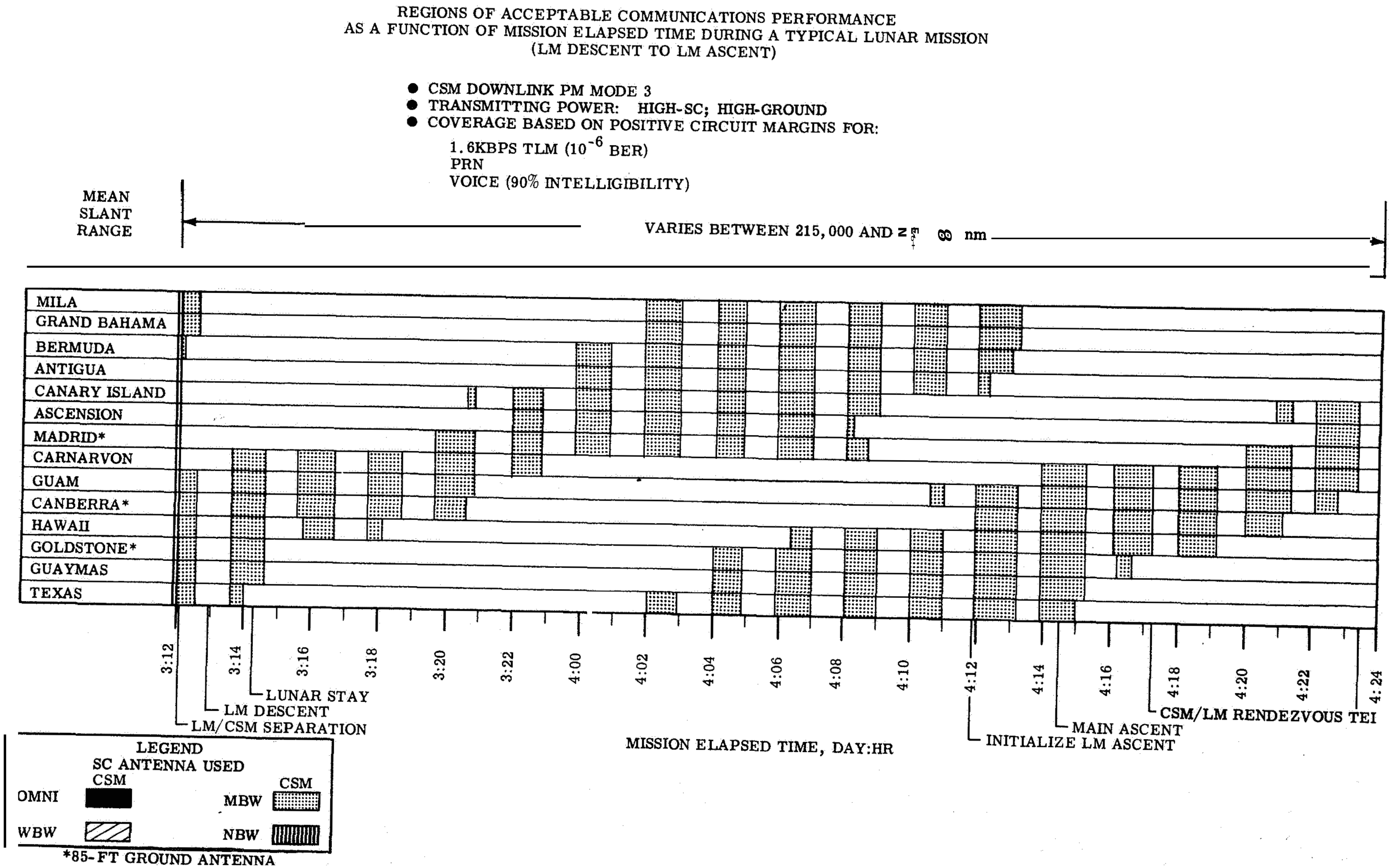


Figure 3-20. CSM Mode 3 Station Coverage; Worst Case, Lunar Orbit

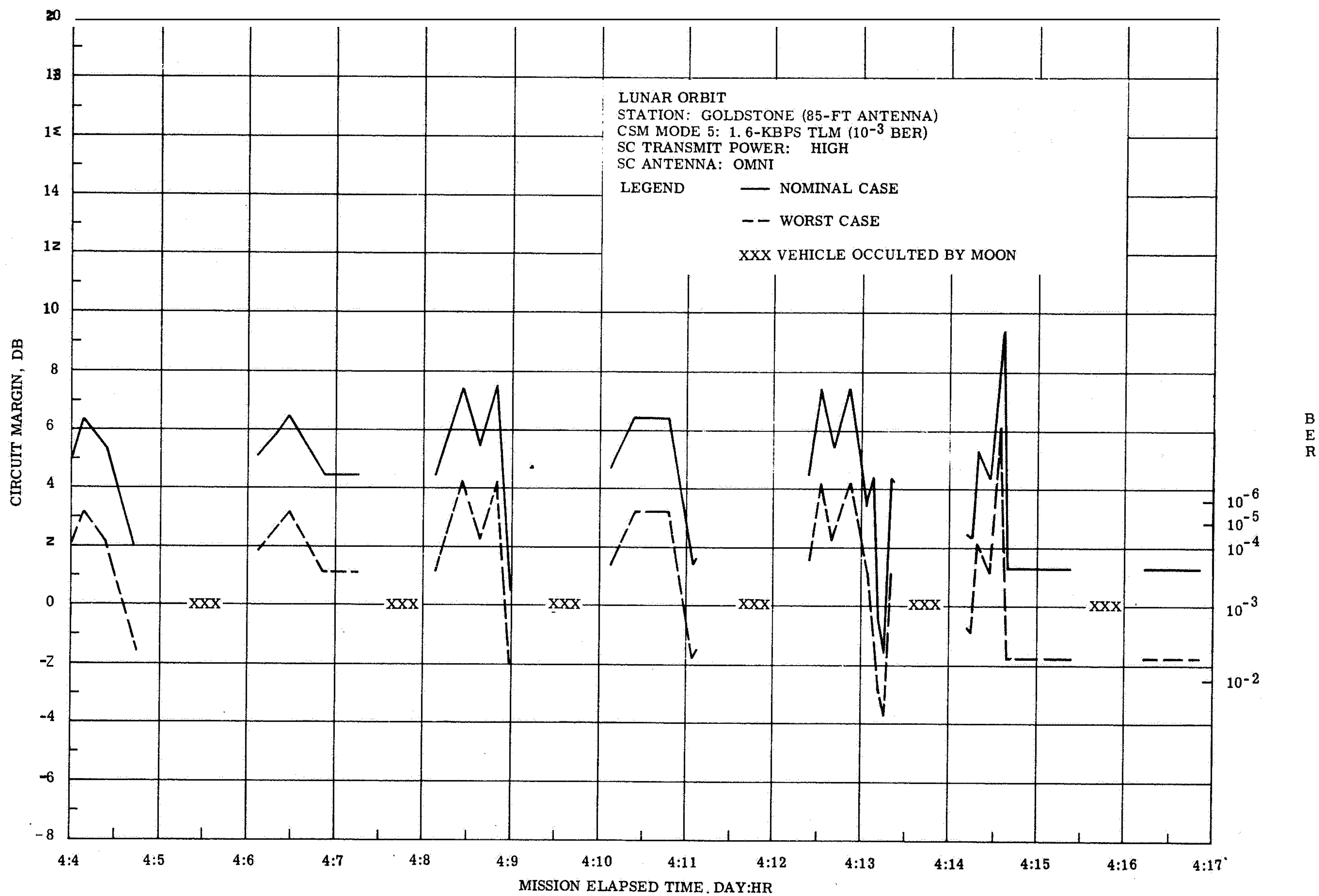


Figure 3-21. CSM Mode 5 Circuit Margin Plot; Nominal and Worst Cases, Lunar Orbit

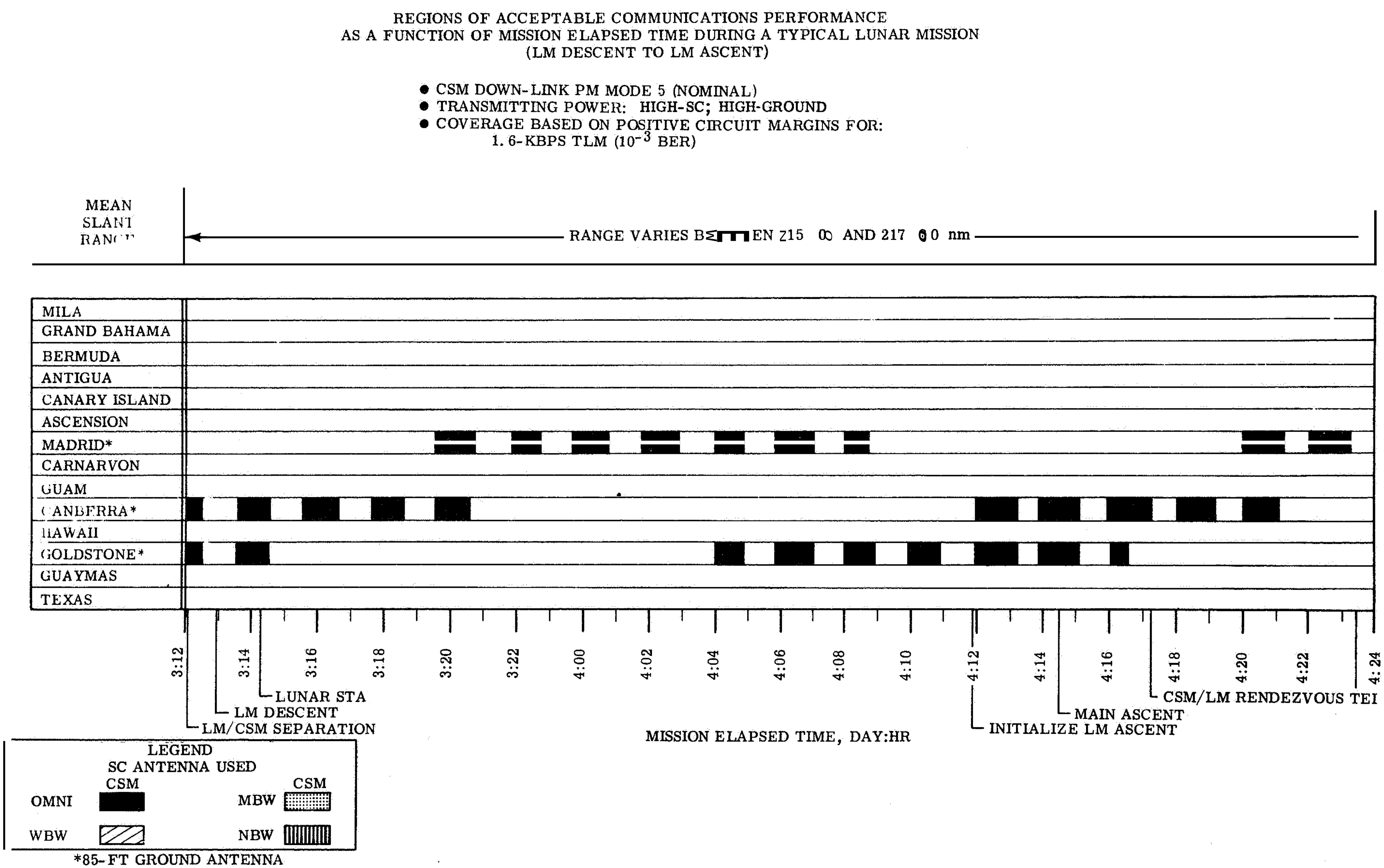


Figure 3-22. CSM Mode 5 Station Coverage; Nominal Case, Lunar Orbit

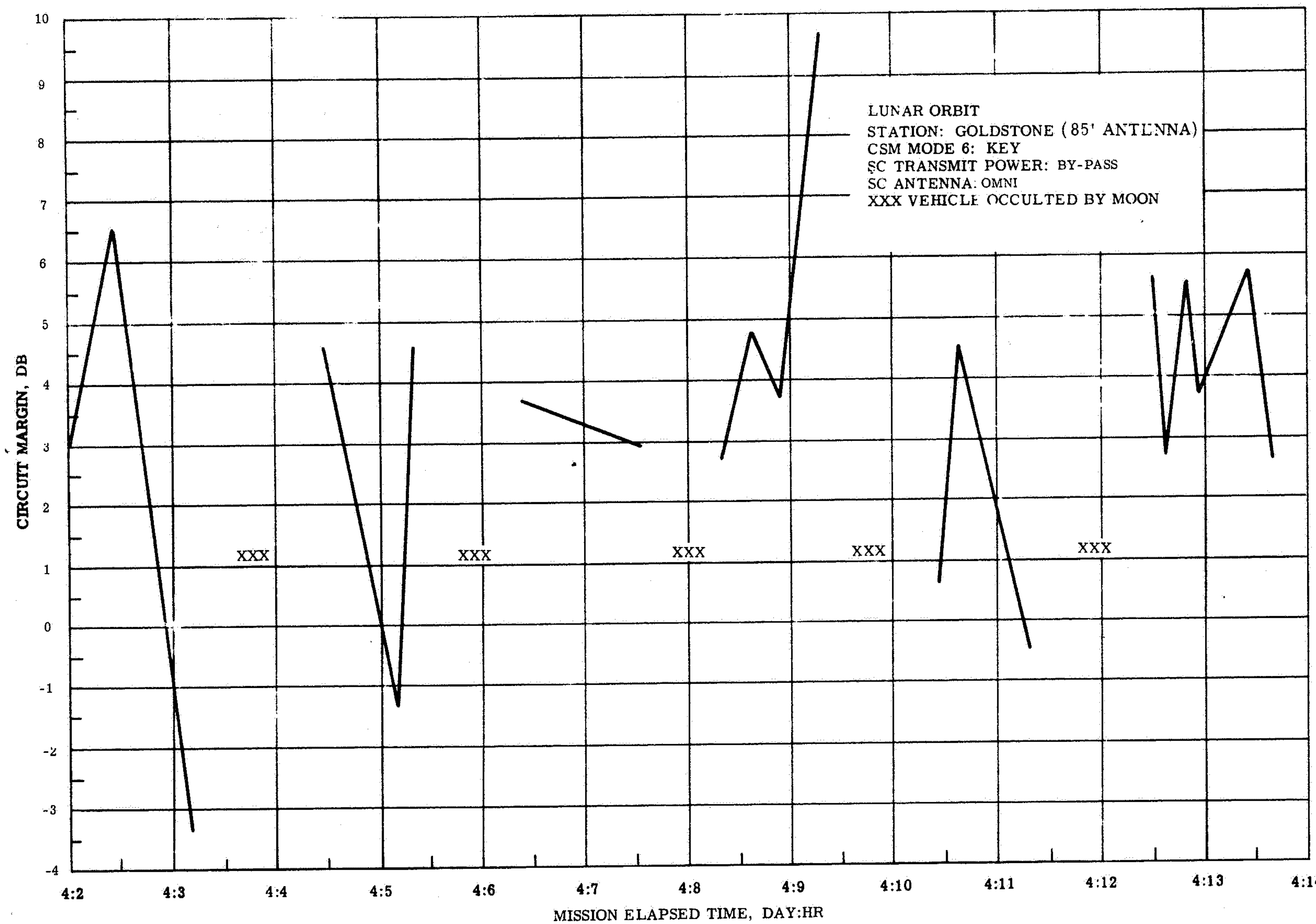


Figure 3-23. CSM Mode 6 Circuit Margin Plot; Worst Case, Lunar Orbit

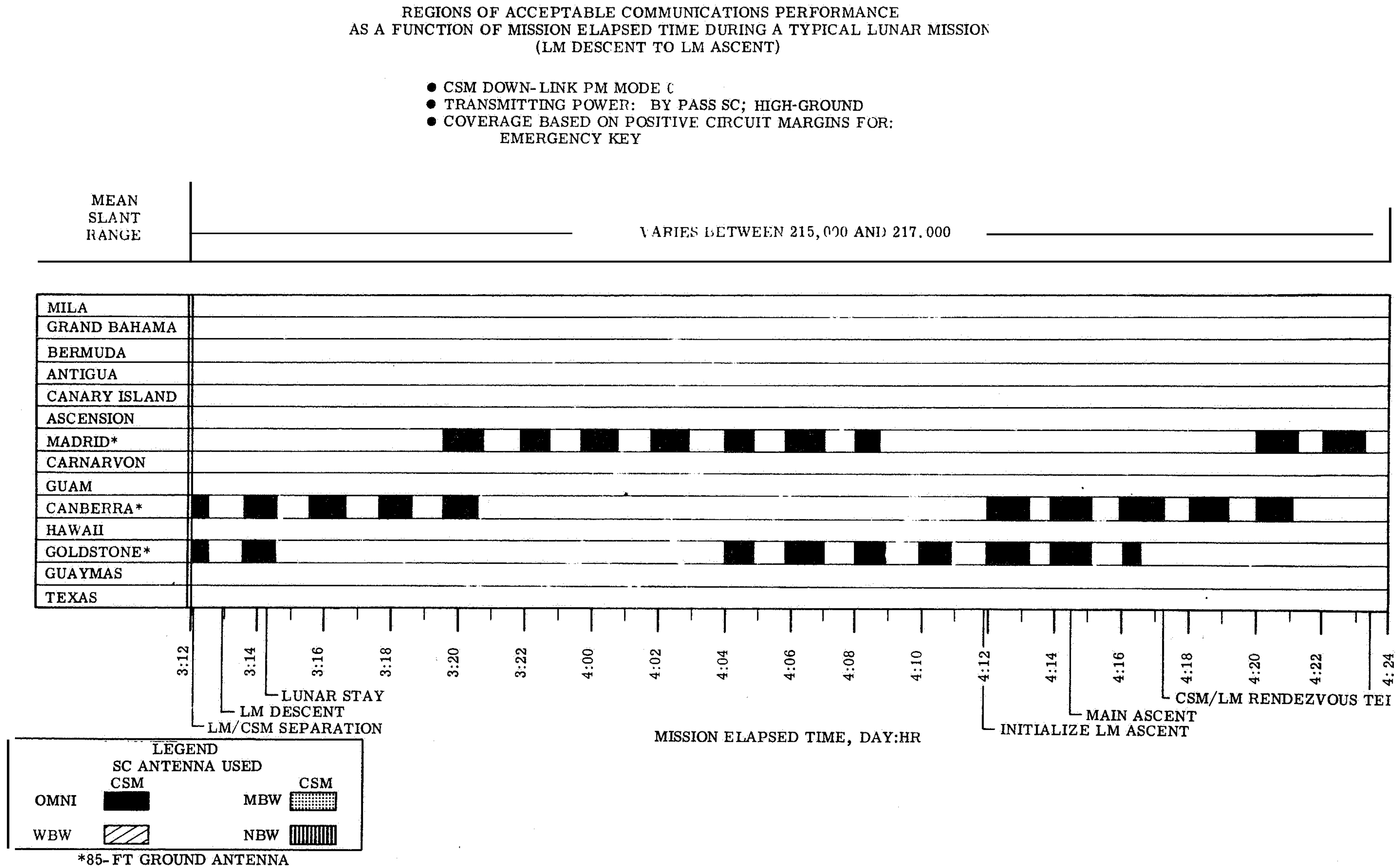


Figure 3-24. CSM Mode 6 Station Coverage; Lunar Orbit

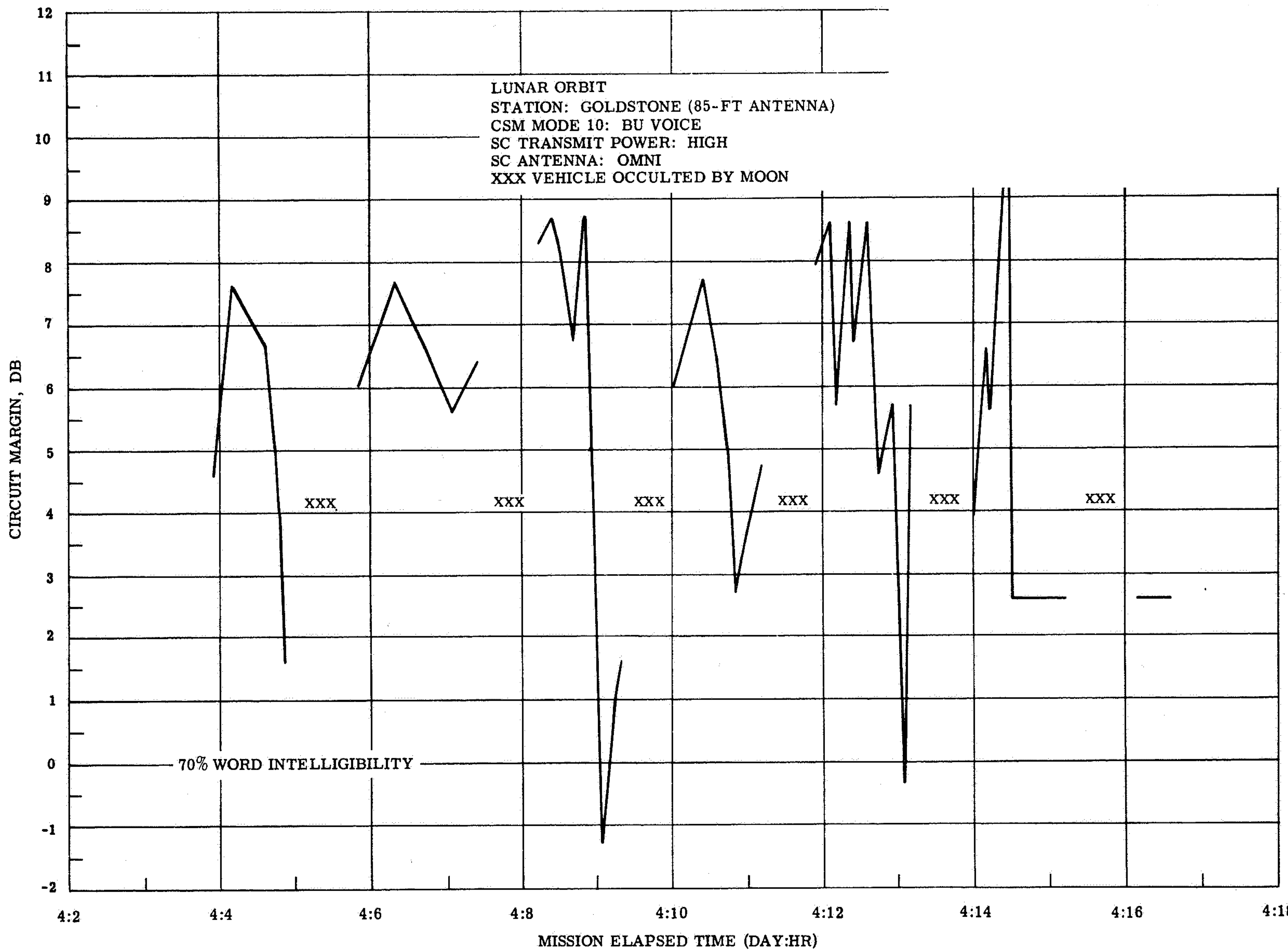


Figure 3-25. CSM Mode 10 Circuit Margin Plot; Worst Case, Lunar Orbit

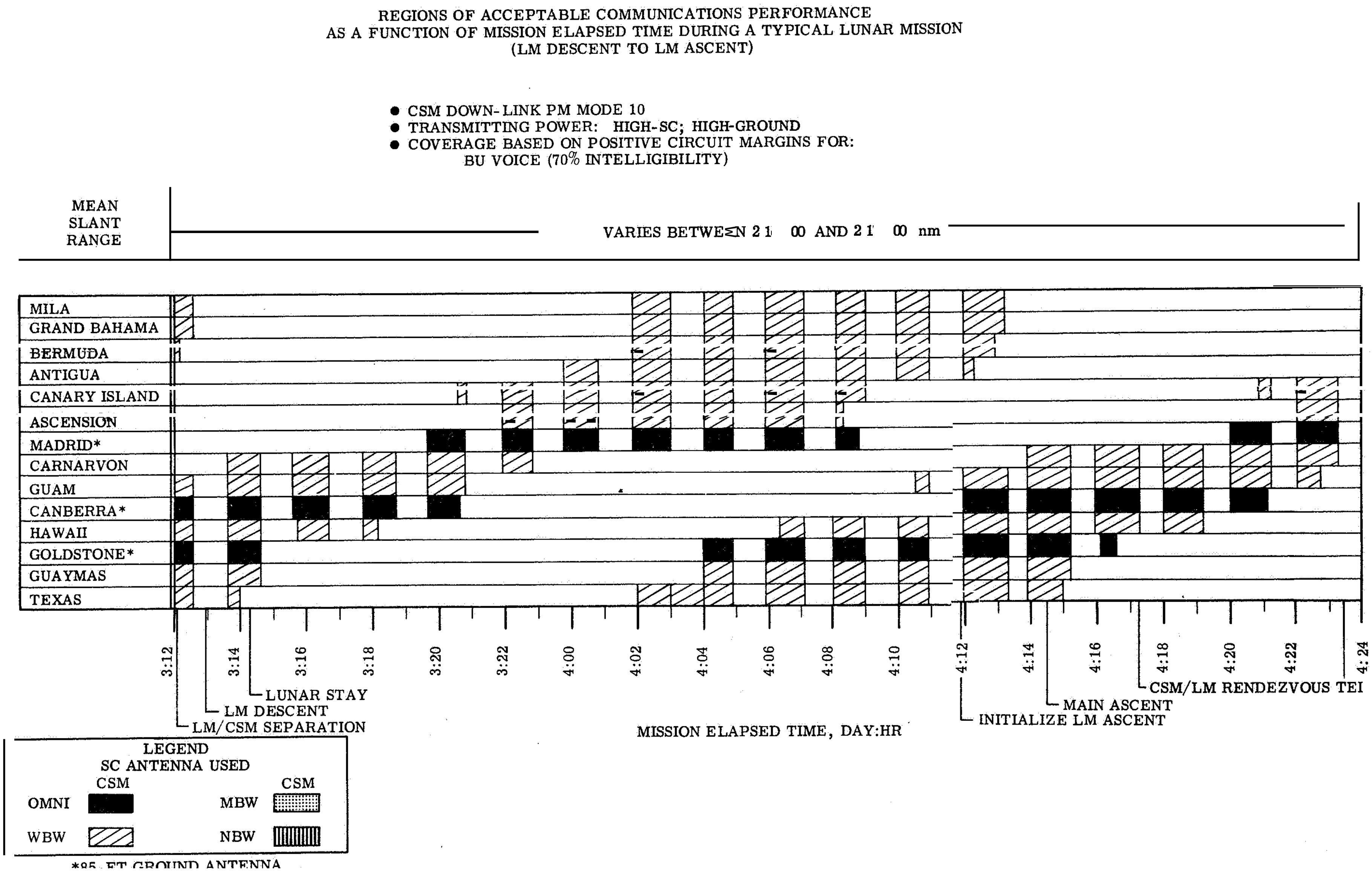


Figure 3-26. CSM Mode 10 Station Coverage; Worst Case, Lunar Orbit

The circuit margins for Mode 6, emergency key, are plotted in Figure 3-23 for the Goldstone 85-foot station. These margins are calculated using the by-pass **power** SC transmitting mode. Negative margins appear for only a small portion of the station coverage time; thus, the 85-foot stations should have acceptable margins when the SC by-pass power mode is used. Figure 3-24 indicates solid coverage for all 85-foot stations using the omni antennas and the 125-milliwatt power output for Mode 6.

The BU voice channel performance is depicted in figures 3-25 and 3-26. As is noted, performance of this mode is satisfactory at lunar distance when using the SC high-output power with an omni antenna and 85-foot MSFN station.

3.2.3 CSM FM Mode 3

As was noted in 3.1.2, FM performance is based on mode-as-a-whole circuit margins (see Appendix C for detailed FM analysis). The performance for FM Modes 1, 2, and 4 is marginal and is discussed in Section 3.1.2 FM Mode 3 has a smaller bandwidth requirement and, as a result, exhibits positive margins at lunar distance. Table 3-4 lists the FM modes and equipment configurations for which circuit margins are calculated in this section.

TABLE 3-4

CSM FM MODES AND ANTENNA/POWER CONFIGURATIONS

Mode	Service(s)	Antenna		Transmit Power		Criteria
		SC	MSFN	SC	MSFN	
FM Mode 1	1:1 Playback of: 51.2Kbps TLM Voice	See Section 3.1.2				Mode-As-A-whole requirement of 8.0 db in bandwidth predetection.
FM Mode 2	32:1 Playback of: 1.6Kbps TLM Voice	See Section 3.1.2				
FM Mode 3	Playback of: LM Split-Phase TLM	High-gain NBW	85-foot	High	High	
FM Mode 4	TV	See Section 3.1.2				

The lunar distance mode-as-a-whole circuit margin for FM Mode 3 is plotted in figure 3-27. Station coverage is indicated in figure 3-28.

3.2.4 LM PM Normal Modes (Modes 1, 2, and 7)

LM PM Modes 1, 2, and 7 are considered the normal LM modes. Modes 1 and 2 are designed to operate with the LM steerable and/or erectable antenna and the SC high-power output. Mode 7 is designed primarily for use during lunar stay. Due to the SC wiring configuration, this mode can be used only with the lower power (.72 watt) output, thus necessitating use of the erectable antenna.

Table 3-5 lists the LM PM normal down-link modes and the equipment configurations for which circuit margins are calculated in this section.

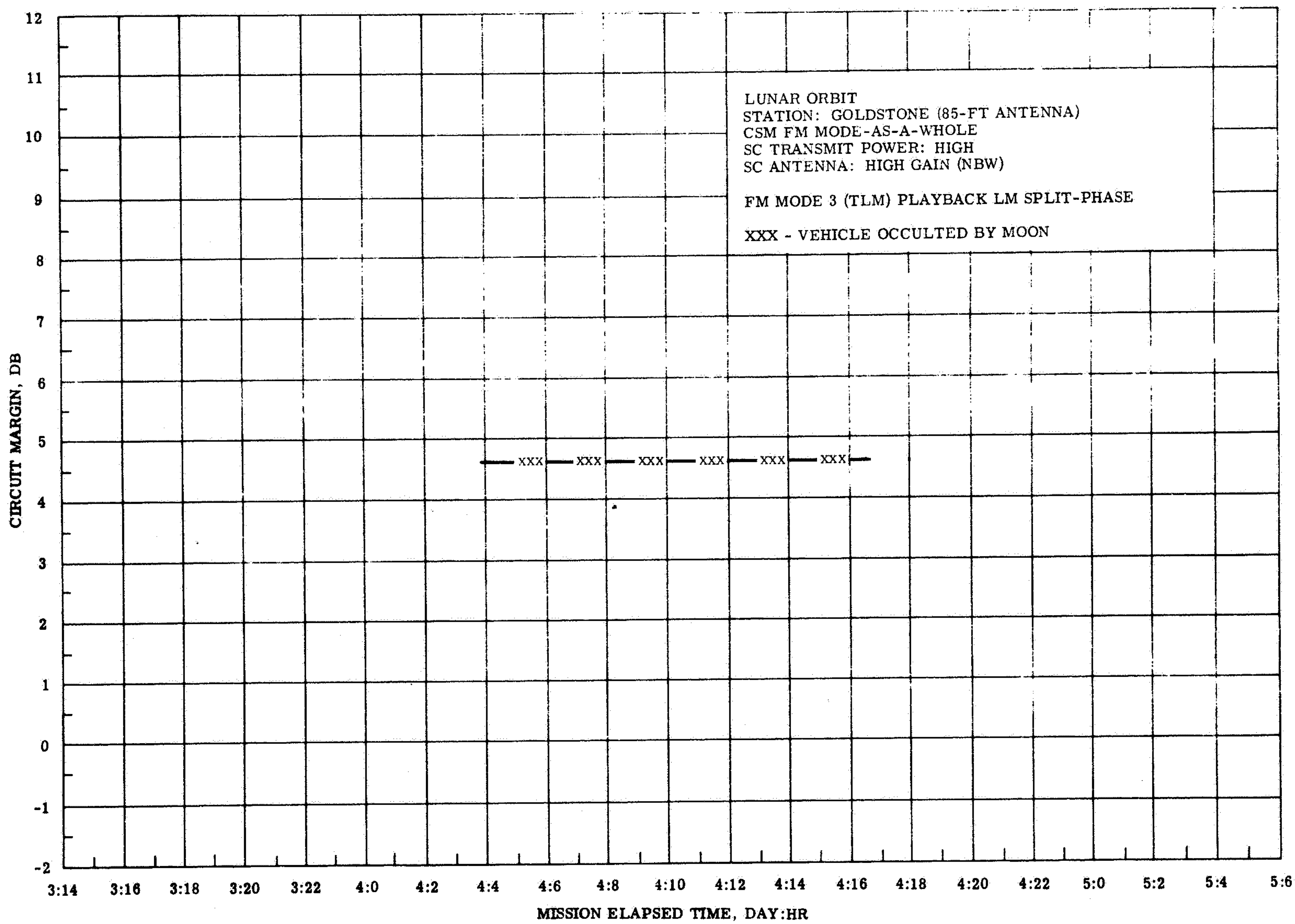
TABLE 3-5

LM PM NORMAL DOWN-LINK MODES AND ANTENNA/POWER CONFIGURATION

Mode	Service(s)	Antenna		Transmit Power		Criteria
		SC	MSFN	SC	MSFN	
LM PM Mode 1	51.2Kbps TLM Voice/HL Biomed	Steerable Erectable	85-foot 30-foot	High	High	10^{-6} BER 90% word intelligibility
LM PM Mode 2	PRN 51.2Kbps TLM Voice/HL Biomed	Steerable Erectable	85-foot 30-foot	High	High	60 second acquisition time 10^{-6} BER 90% word intelligibility
LM PM Mode 7	1.6Kbps TLM Voice/HL Biomed	Erectable	85-foot	Low	High	10^{-6} BER 90% word intelligibility

Figures 3-29 and 3-30 depict the circuit margins for LM Mode 1 at the MILA 30-foot station using the steerable and erectable antennas. It is noted that the TLM margins are slightly negative when using the LM steerable antenna. Figures 3-31 and 3-32 show the Mode 1 margins for the 85-foot station at Goldstone. The margins are positive for both the LM steerable and LM erectable antennas. Figure 3-33 defines the station coverage for LM Mode 1.

LM Mode 2 circuit margins for the MILA 30-foot station are shown in Figures 3-34 and 3-35 for the LM steerable and erectable antennas respectively. With the erectable antenna, the 30-foot MSFN stations provide satisfactory performance in Mode 2. Use of the LM steerable



Note: Experimental data indicates that the 8.0db mode-as-a-whole criterion is not adequate for all FM modes. (See Appendix C.)

Figure 3-27. CSM FM Mode-As-A-Whole (FM Mode 3) Circuit Margin Plot; Worst Case Lunar Orbit

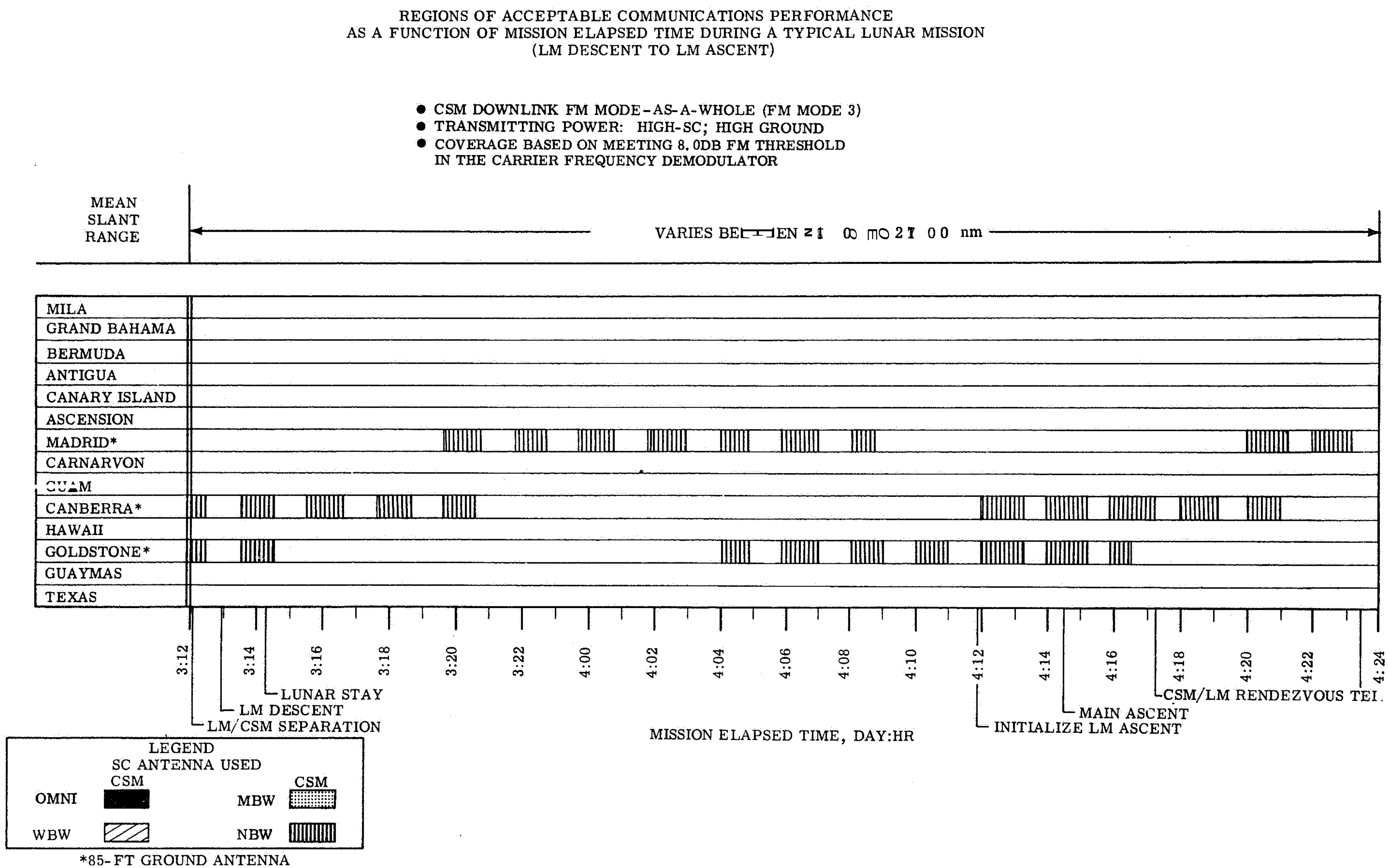


Figure 3-28. CSM FM Mode-As-A-Whole (FM Mode 3) Station Coverage; Worst Case, Lunar Orbit

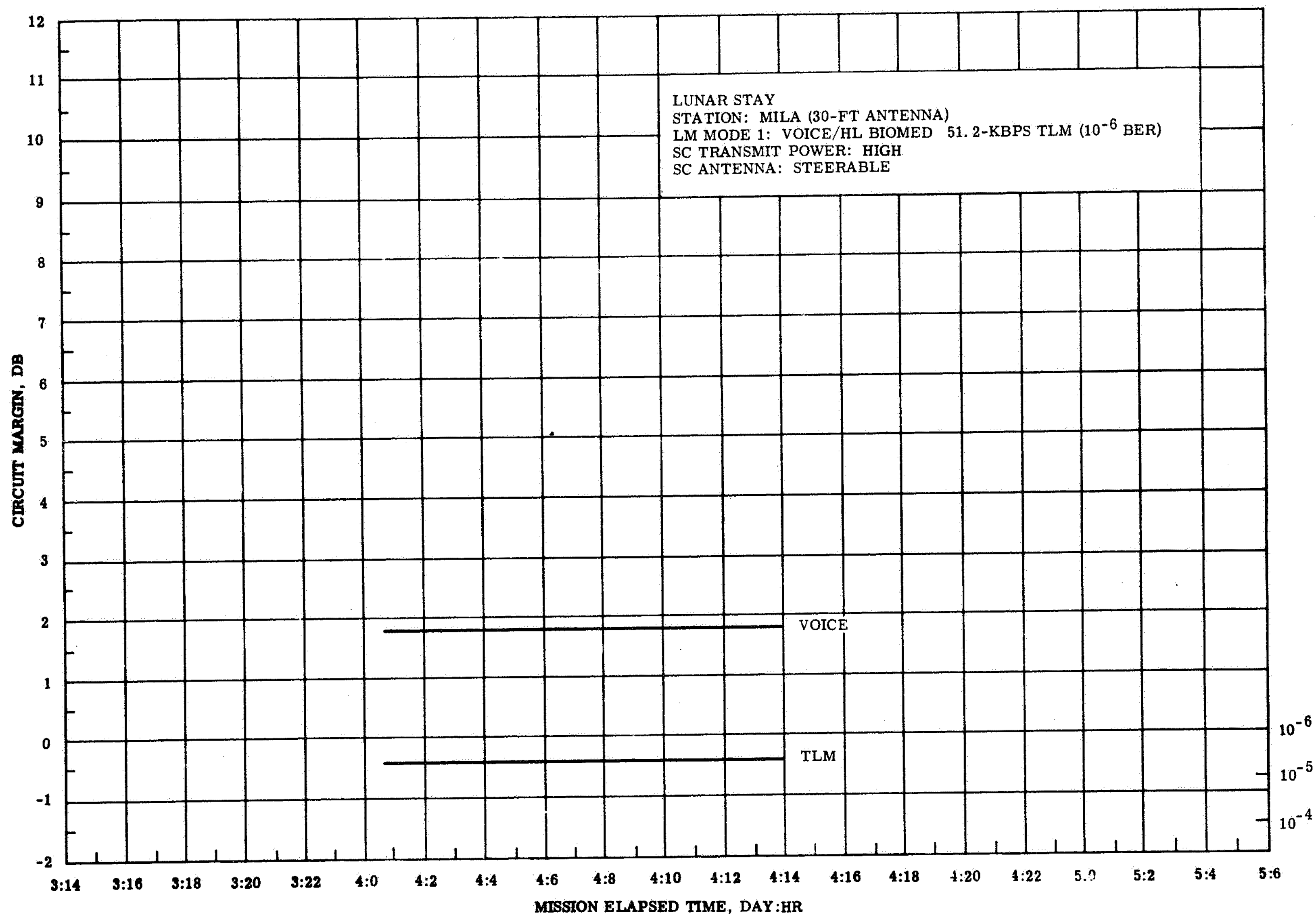


Figure 3-29. LM Mode 1 Circuit Margin Plot; Steerable Antenna, Worst Case, Lunar Stay

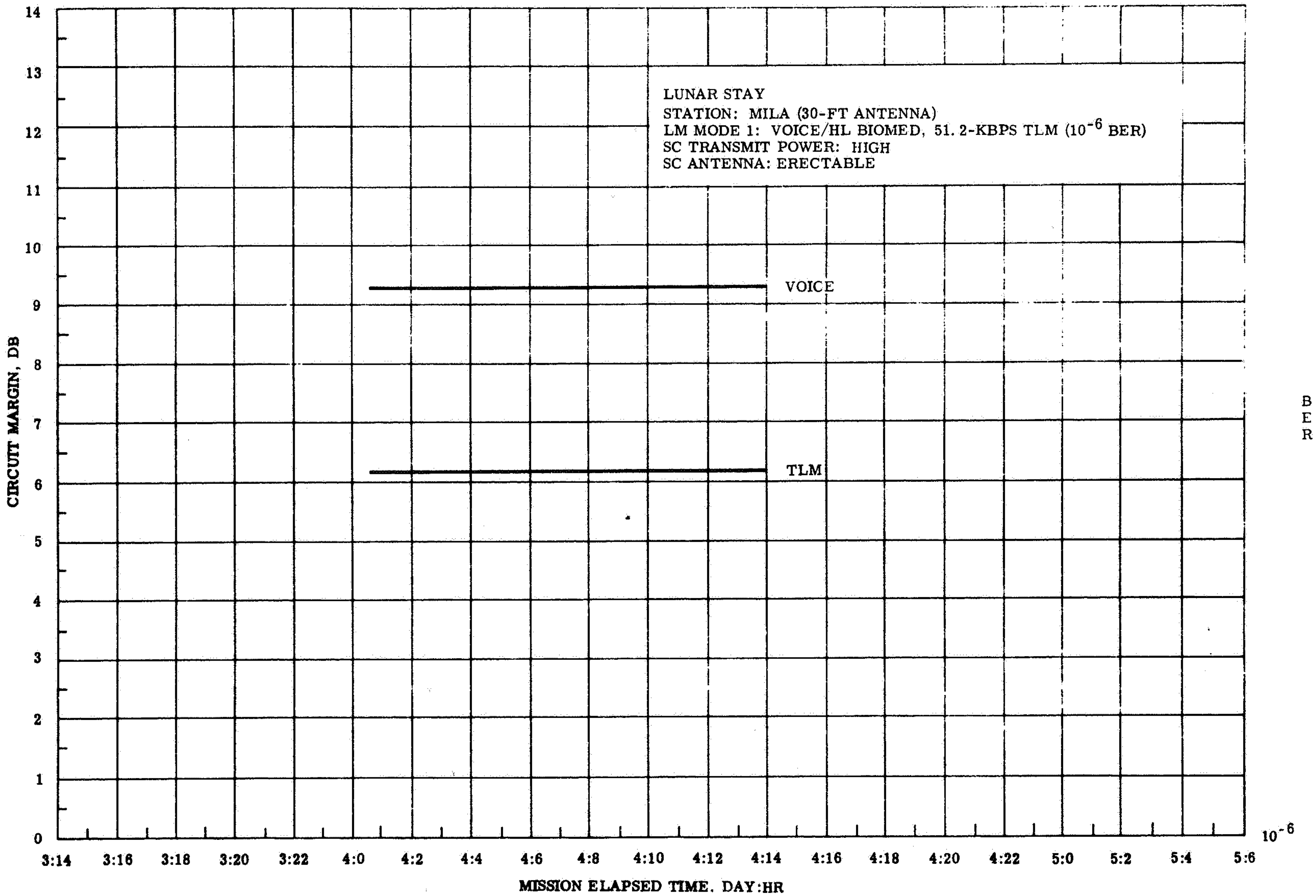


Figure 3-30. LM Mode 1 Circuit Margin Plot; Erectable Antenna, Worst Case, Lunar Stay

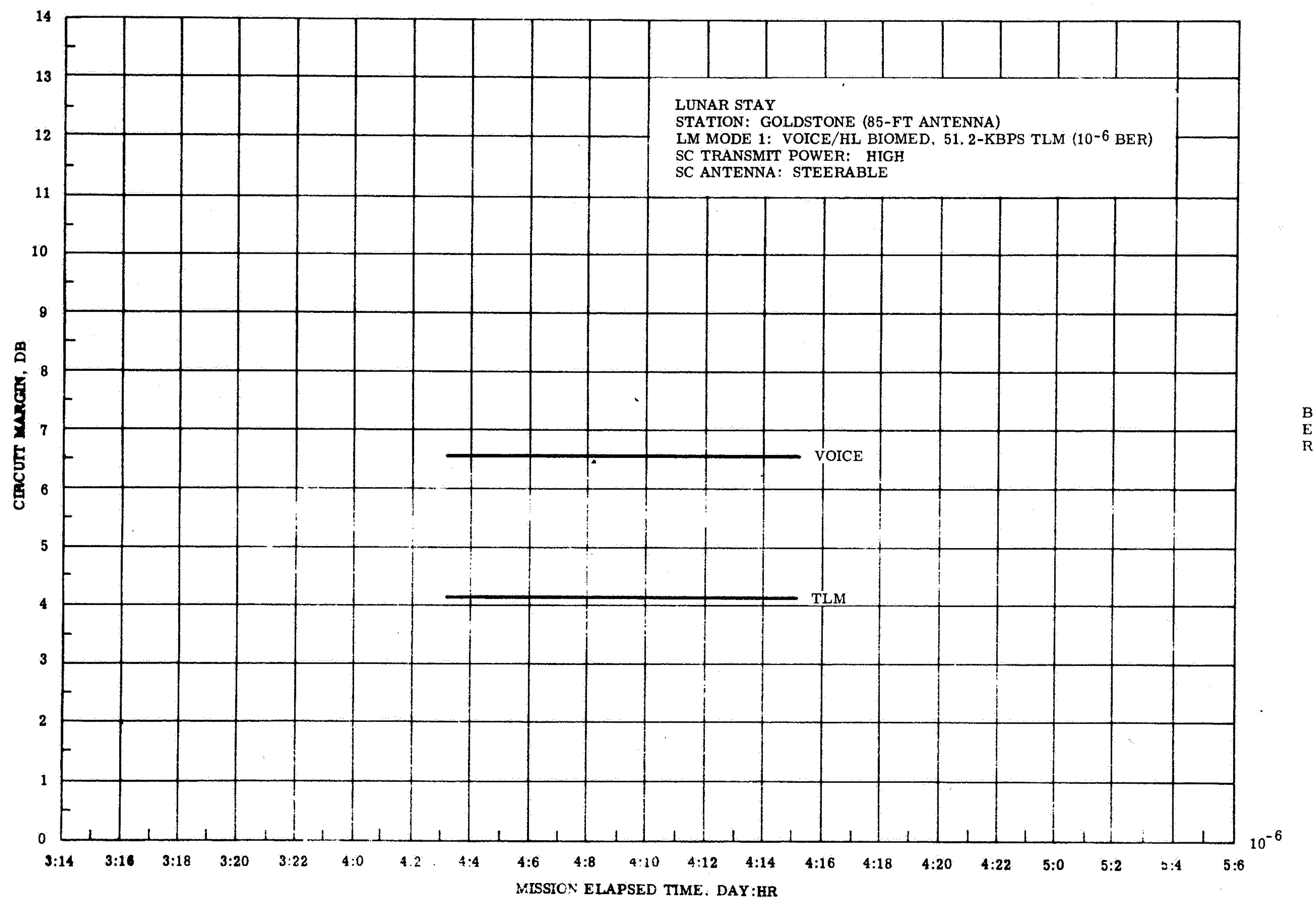


Figure 3-31. LM Mode 1 Circuit Margin Plot; Steerable Antenna, Worst Case, Lunar Stay

B
E
R

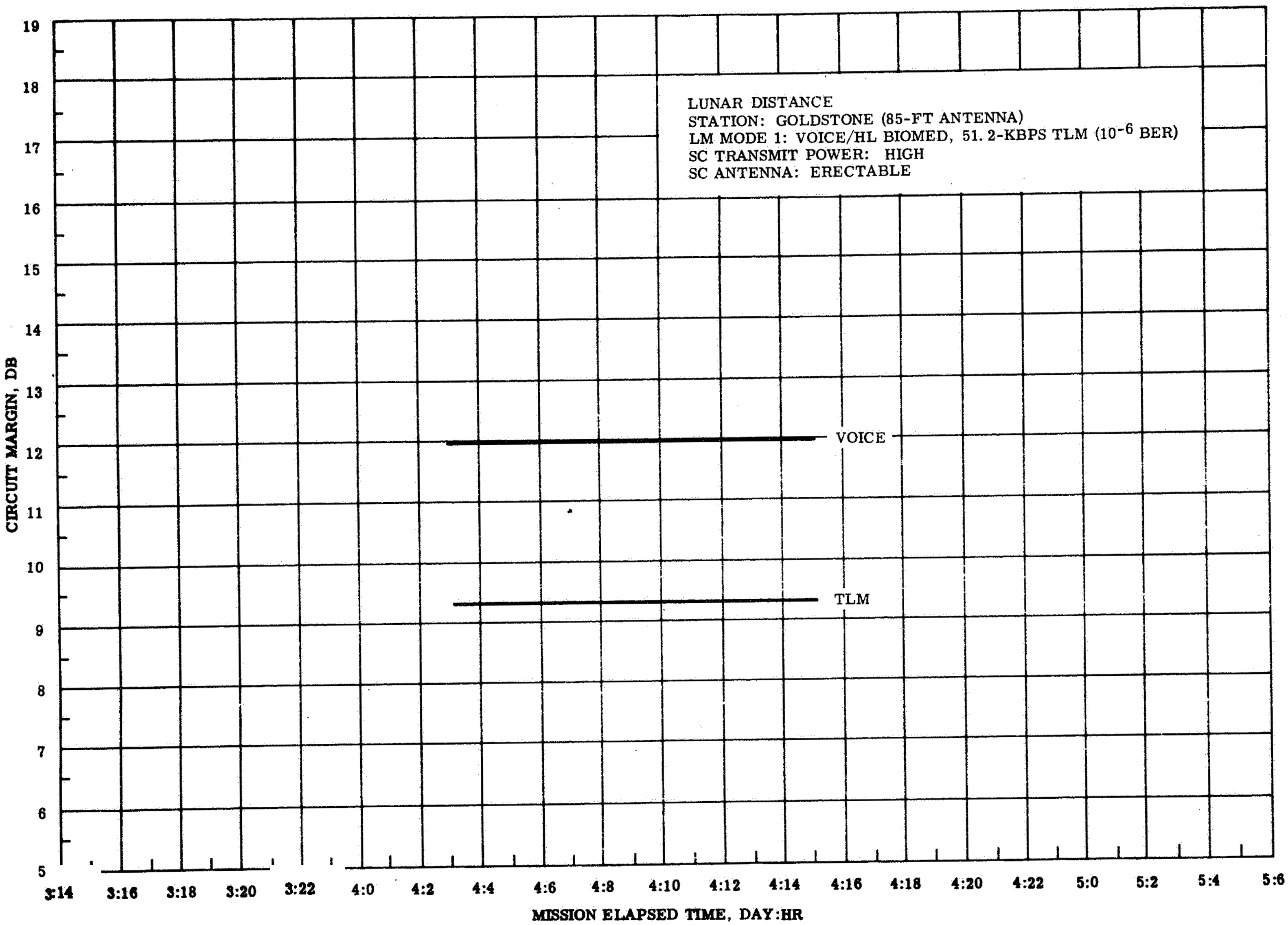


Figure 3-32. LM Mode 1 Circuit Margin Plot; Erectable Antenna, Worst Case, Lunar Stay

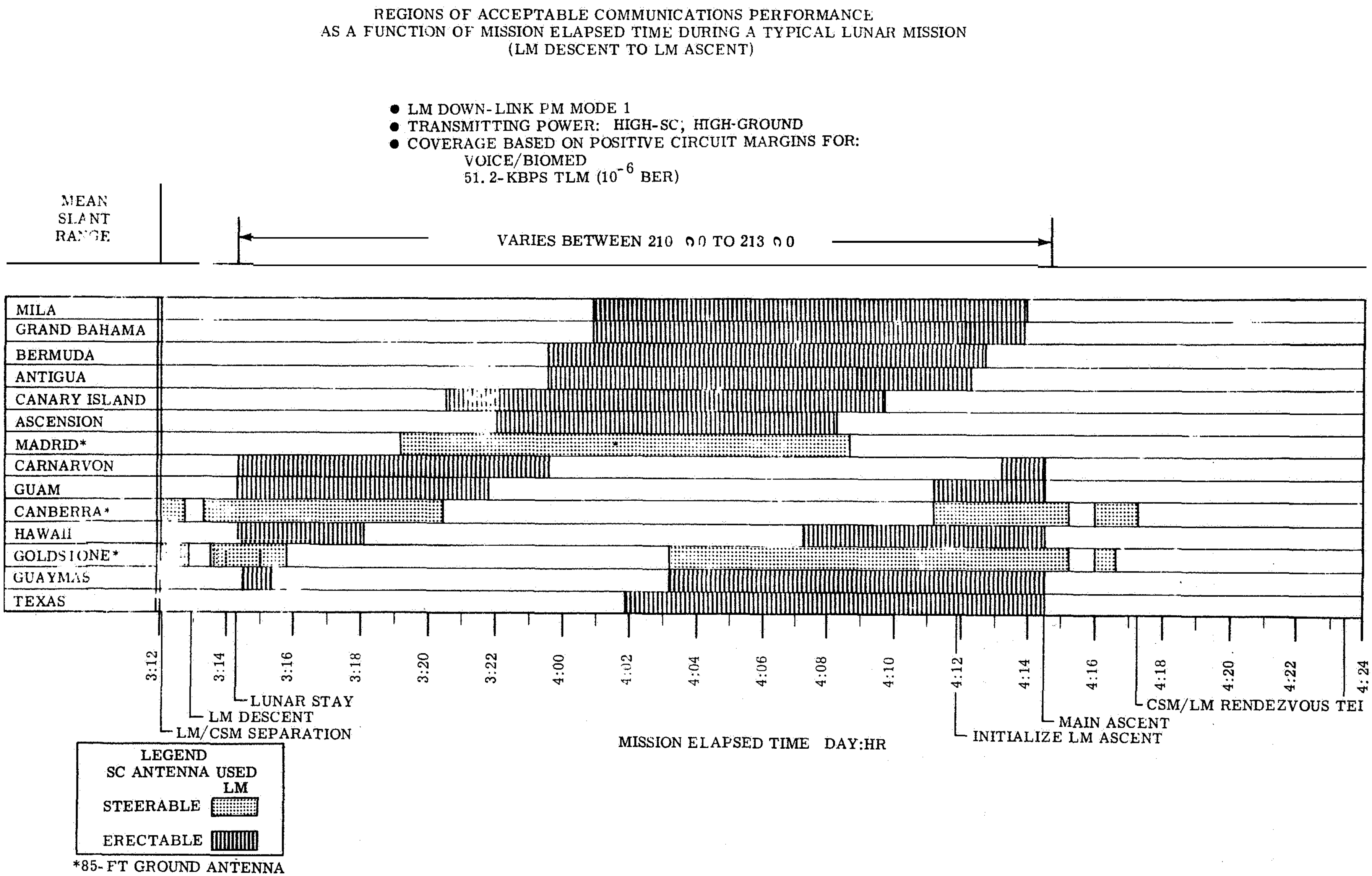


Figure 3-33. LM Mode 1 Station Coverage; Worst Case, Descent-Ascent

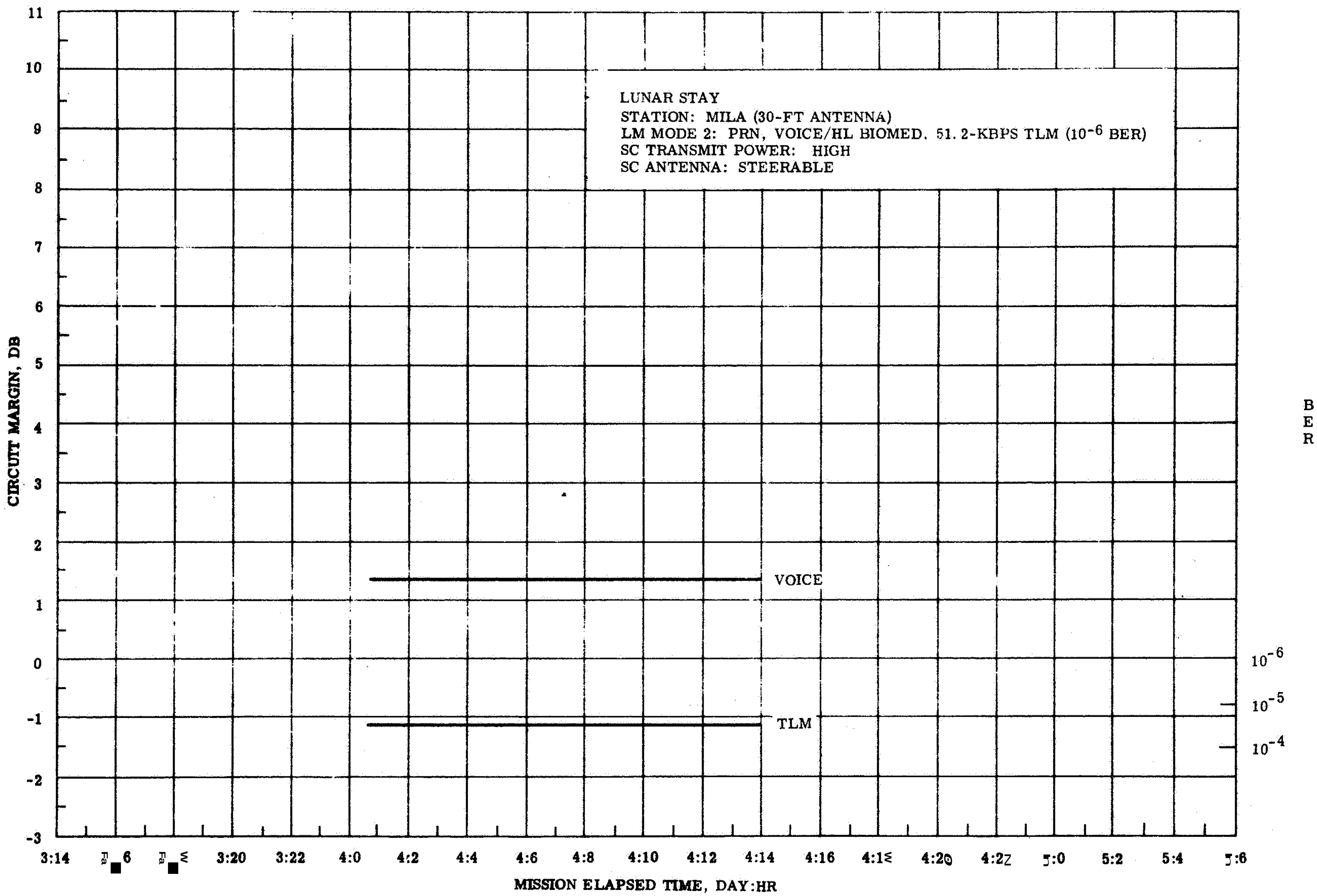


Figure 3-34. LM Mode 2 Circuit Margin Plot, Steerable Antenna; Worst Case, Lunar Stay

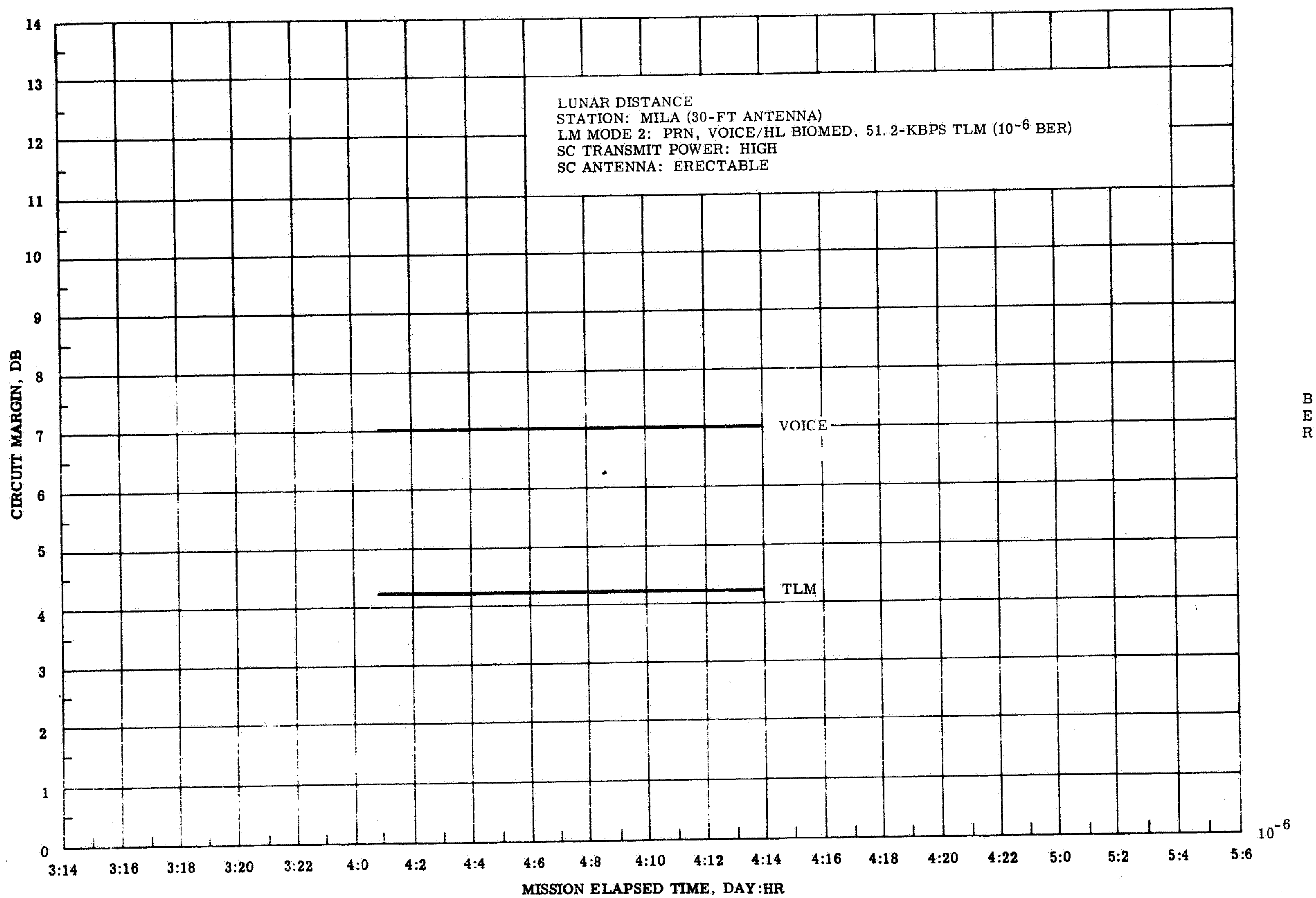


Figure 3-35. LM Mode 2 Circuit Margin Plot, Erectable Antenna; Worst Case, Lunar Distance

antenna limits satisfactory reception of Mode 2 to the 85-foot stations. Figure 3-36 shows the Mode 2 margins for the 85-foot station at Goldstone. Station coverage for LM Mode 2 is defined in figure 3-37. Mode 2 coverage during the descent and ascent phases is limited to the 85-foot MSFN stations.

The lunar stay mode (Mode 7) circuit margins are depicted in figure 3-38 for the 30-foot stations and in figure 3-39 for the 85-foot stations. It is noted that with the erectable antenna, positive 1.6Kbps TLM margins are obtained with both the 85-foot and the 30-foot MSFN stations. Voice margins are slightly negative with the erectable antenna and 30-foot station. Without the erectable antenna, negative margins prevail at all stations. Figure 3-40 indicates the station coverage for Mode 7.

3.2.5 LM PM Contingency Modes (Modes 3, 5, 6, and 8)

The LM PM contingency modes operate with the LM omni antennas and/or the low-output power mode. Full-scale pattern data were not available on the LM omni antennas at the time the computer calculations for this report were made. Thus, all backup mode circuit margins, except for Mode 8, are calculated using a nominal -3db SC antenna gain. Mode 8 margins are calculated using the steerable antenna/high power output and erectable antenna/low power output configurations.

Table 3-6 lists the LM contingency modes and the equipment configurations used for the circuit margin calculations in this section.

Circuit margins at the 85-foot station at Goldstone for LM Mode 3 are shown in figure 3-41. Figure 3-42 shows the station coverage for LM Mode 3 based on nominal margin calculations.

TABLE 3-6

LM PM CONTINGENCY MODES AND ANTENNA/POWER CONFIGURATIONS

Modes	Service(s)	Antenna		Transmit Power		Criteria
		SC	MSFN	SC	MSFN	
LM PM Mode 3	1.6Kbps TLM	Omni	85-foot	High	High	10^{-3} BER
LM PM Mode 4	Voice 1.6Kbps TLM	Omni	85-foot	High	High	See Section 3.1.3
LM PM Mode 5	BU Voice	Omni	85-foot 30-foot	High	High	70% word intelligibility

TABLE 3-6 (Continued)

Modes	Service(s)	Antenna		Transmit Power		Criteria
		SC	MSFN	SC	MSFN	
LM PM Mode 6	Emergency Key	Omni	85-foot	Low	High	20 characters per minute; 60% copying'accuracy
LM Special Mode 8	1.6 Kbps TLM Voice/HL Biomed/EMU	Erectable Steerable	85-foot	Low High	N/A	10^{-6} BER 70% word intelligibility

LM Mode 5 provides backup voice at baseband. Both the nominal. and worst case circuit margins are positive for the -3db SC antenna when using the 85-foot MSFN antenna as shown in figure 3-43. Considering only the nominal case conditions, satisfactory performance of Mode 5 is also possible at the 30-foot MSFN stations. Figure 3-44 shows the station coverage based on the nominal case circuit margin calculations.

Figure 3-45 depicts the performance of the emergency key channel (Mode 6) using a -3db omni antenna and the LM low-power output. Margins are included only for the 85-foot stations since key demodutors are not implemented at the 30-foot stations. Figure 3-46 shows station coverage based on worst case circuit margin calculations.

LM Mode 8 is a special mode designed for use in the event of a failure in the 1.25 MHz subcarrier oscillator. This mode is not designed to operate using omni antennas; therefore, the circuit margins are calculated using the LM steerable and erectable antennas. Figure 3-47 is the circuit margin plot for all services of Mode 8 using the LM steerable antenna and high power output. Figure 3-48 shows the station coverage for this configuration. Circuit margin plots and station coverage charts for the erectable antenna with low power output are shown in Figures 3-49 and 3-50 respectively.

3.2.6 LM FM Modes

The LM USB system operates with either a PM carrier or an FM carrier, but not with both simultaneously. The FM capability presented here is thus valid only when a PM mode is not required. Table 3-7 lists the LM FM modes and the equipment configurations used in the circuit margin calculations.

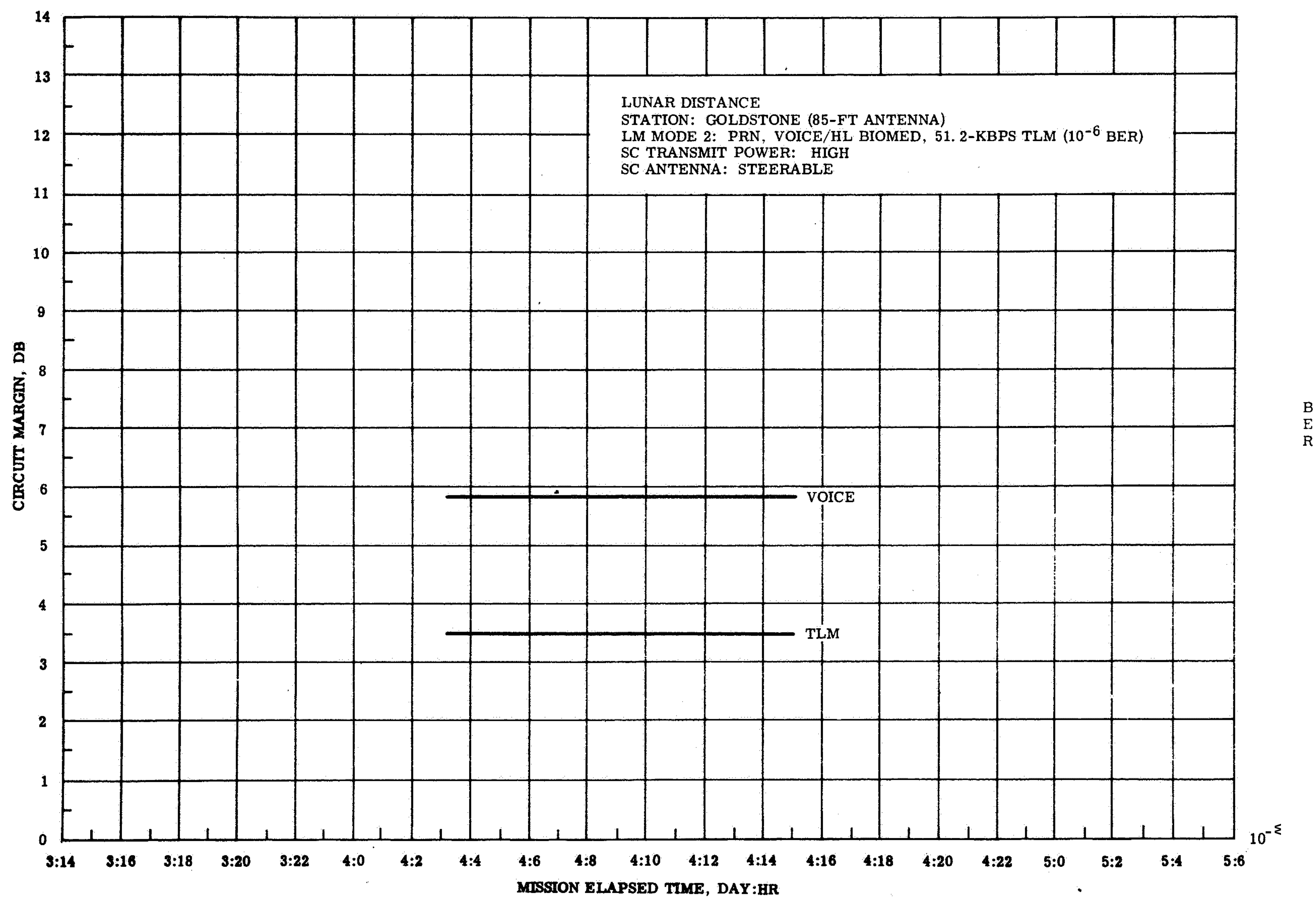


Figure 3-36. LM Mode 2 Circuit Margin Plot, Steerable Antenna; Worst Case, Lunar Distance

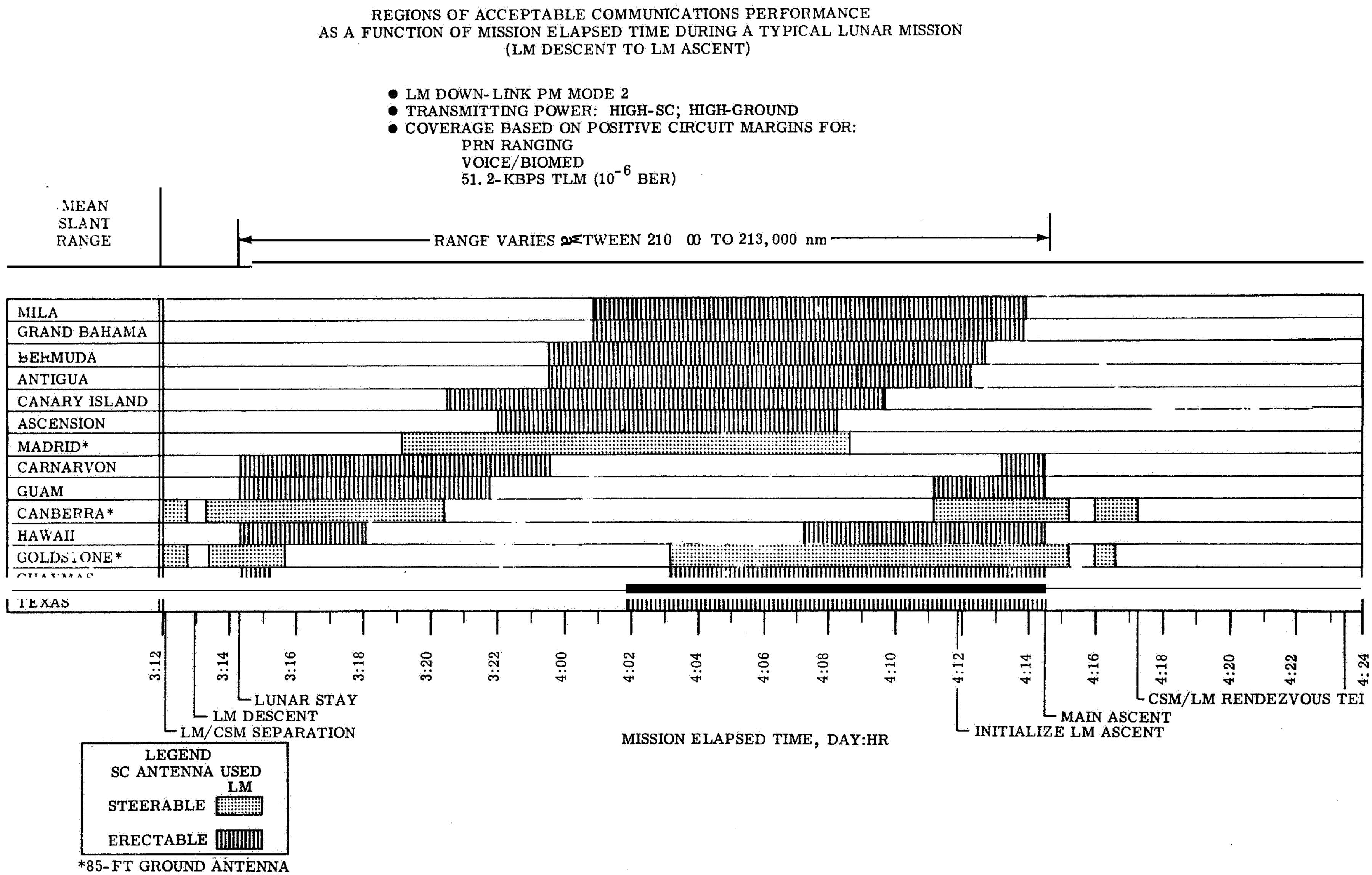


Figure 3-37. LM Mode 2 Station Coverage, Worst Case, Lunar Stay

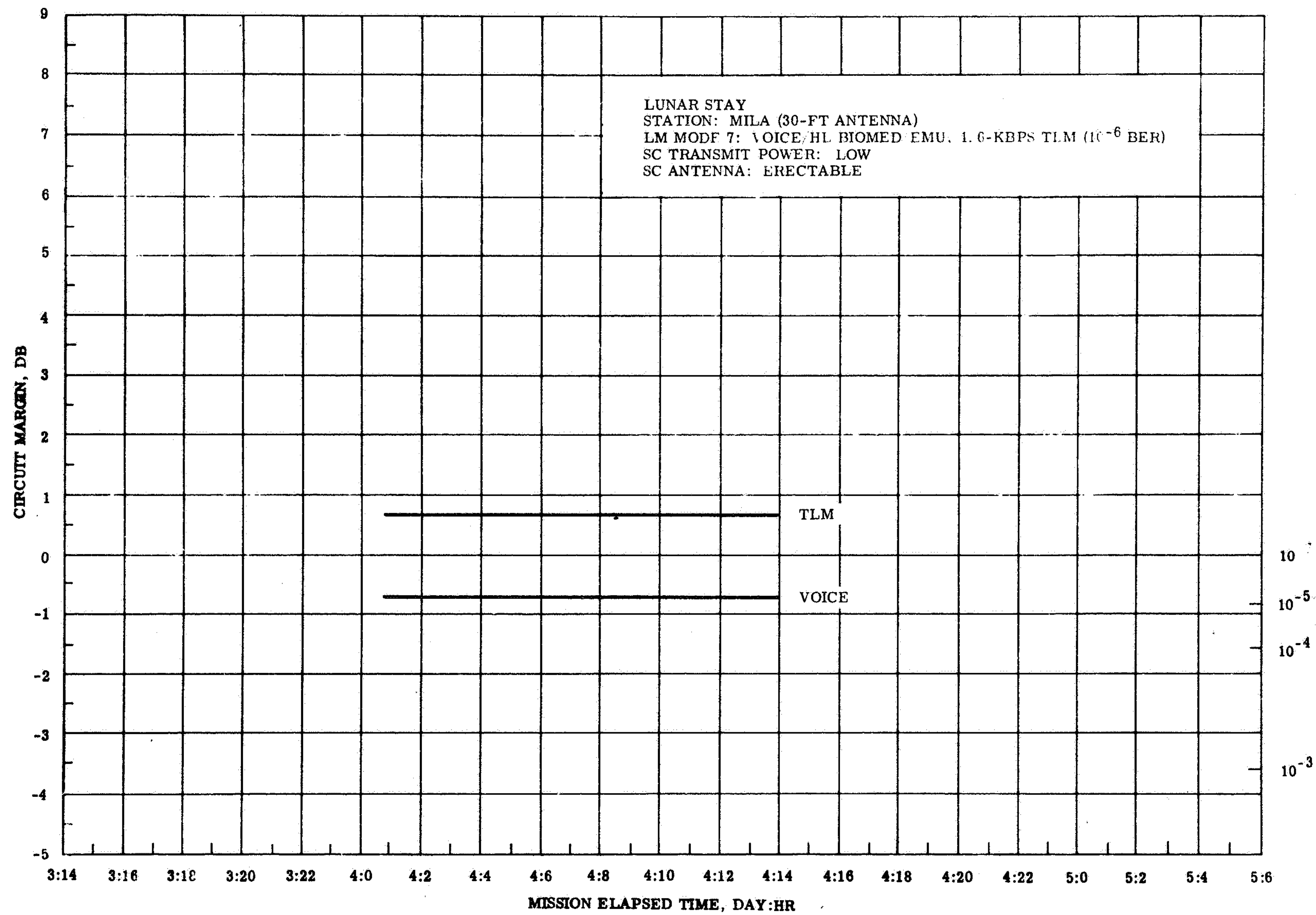


Figure 3-38. LM Mode 7 Circuit Margin Plot, Erectable Antenna; Worst Case, Lunar Stay

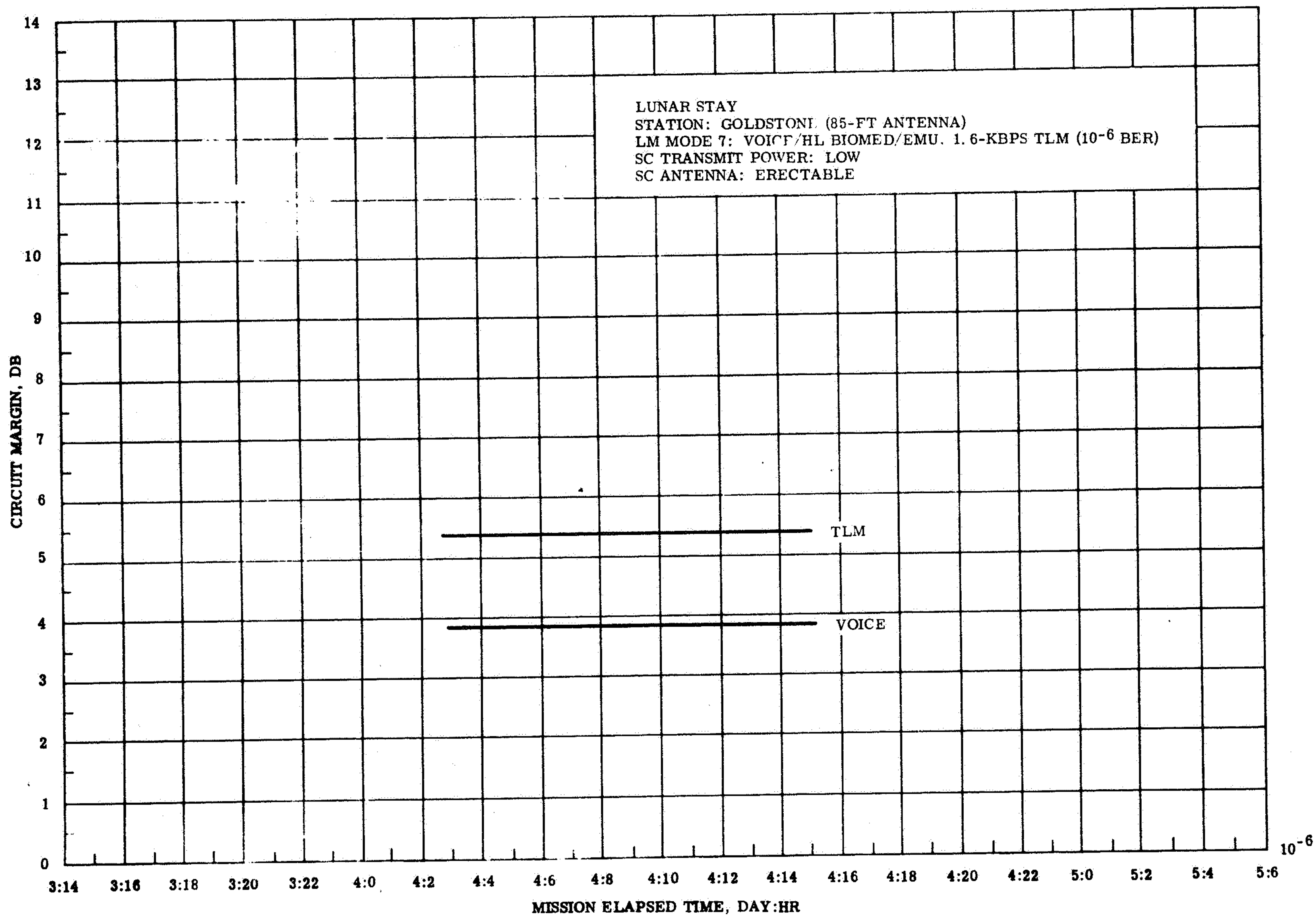


Figure 3-39. LM Mode 7 Circuit Margin Plot, Erectable Antenna; Worst Case, Lunar Stay

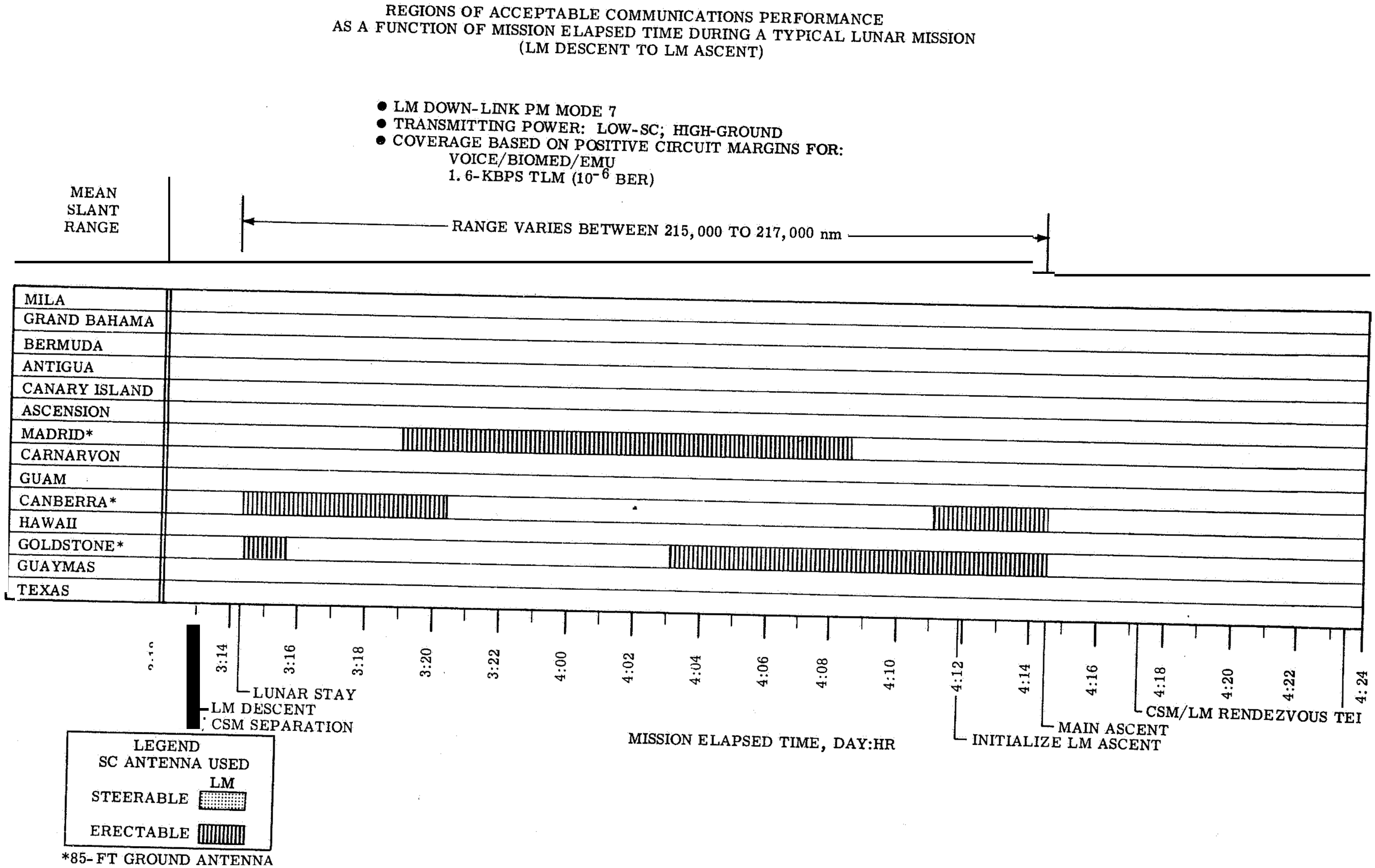


Figure 3-40. LM Mode 7 Station Coverage; Worst Case, Lunar Stay

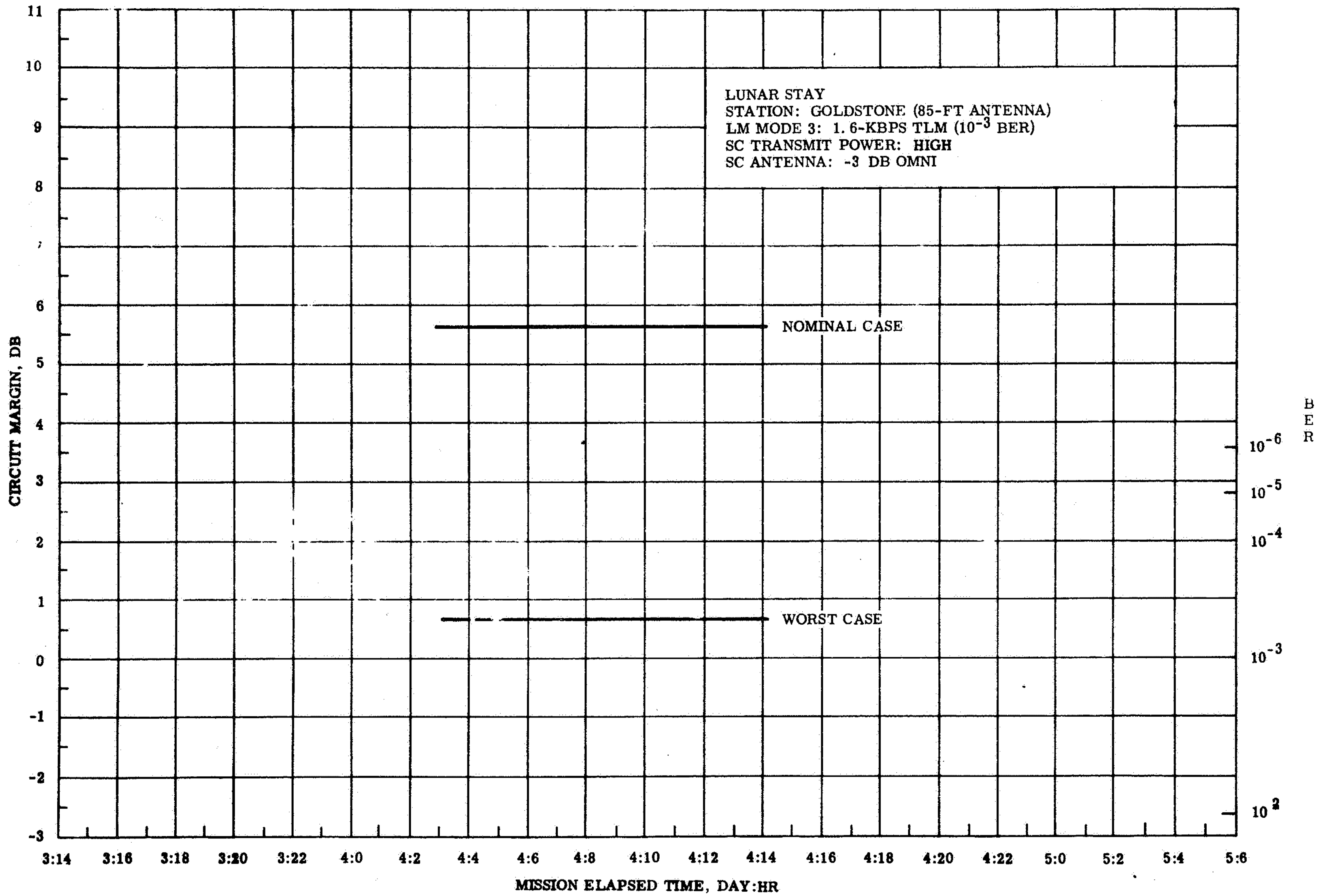


Figure 3-41. LM Mode 3 Circuit Margin Plot, Nominal and Worst Cases, Lunar Stay

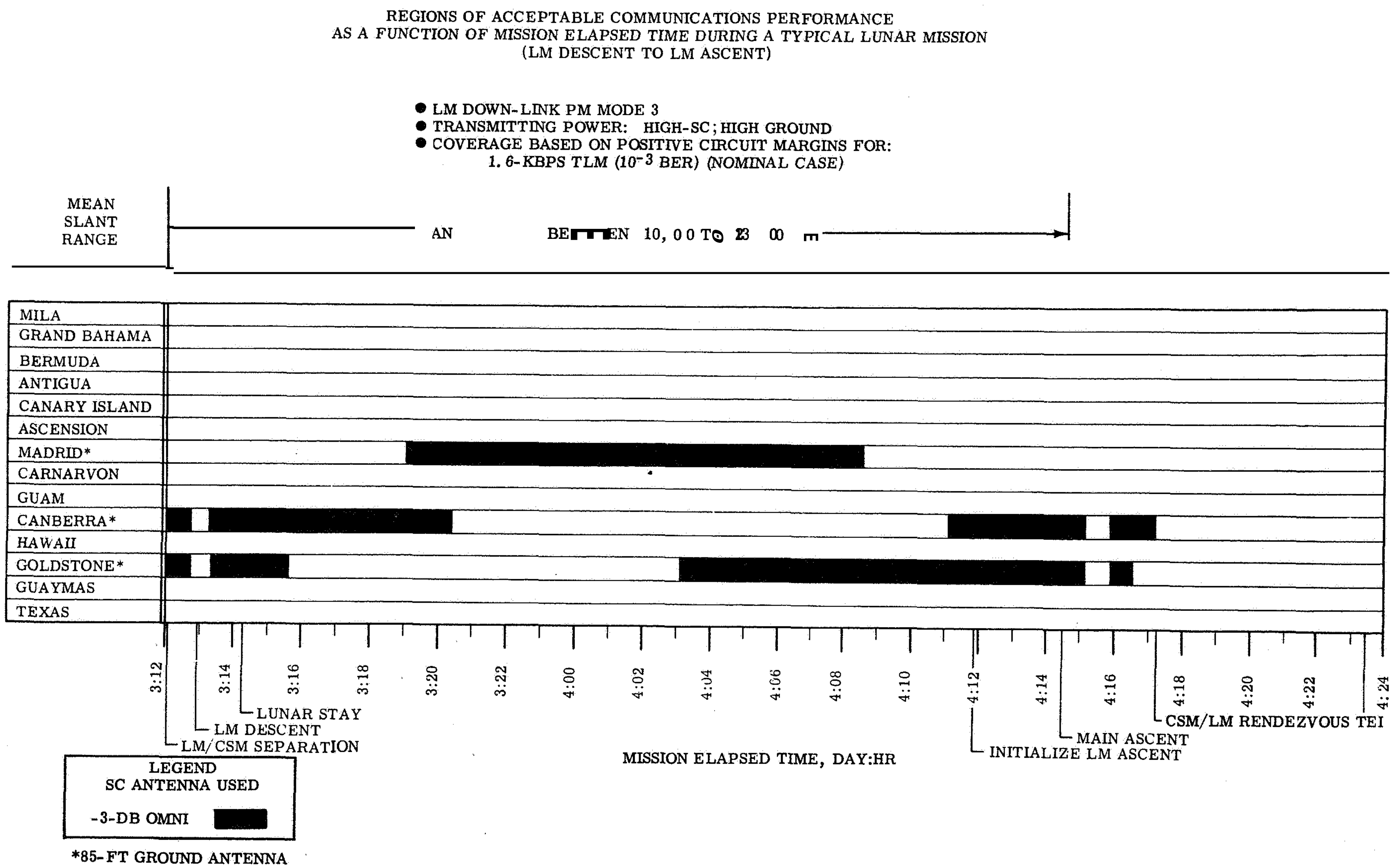


Figure 3-42. LM Mode 3 Station Coverage; Nominal Case, Lunar Stay

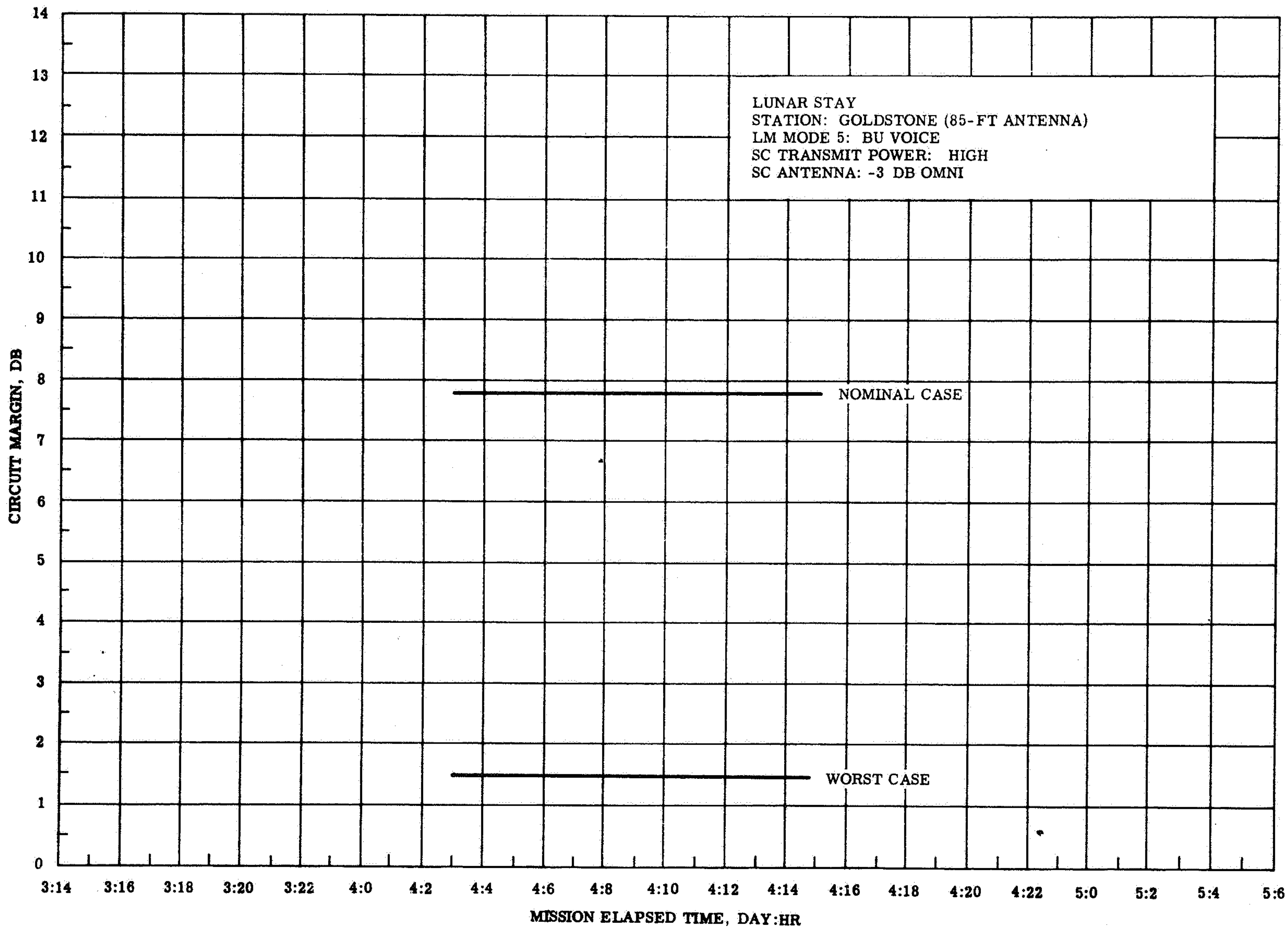


Figure 3-43. LM Mode 5 Circuit Margin Plot; Nominal and Worst Cases, Lunar Stay

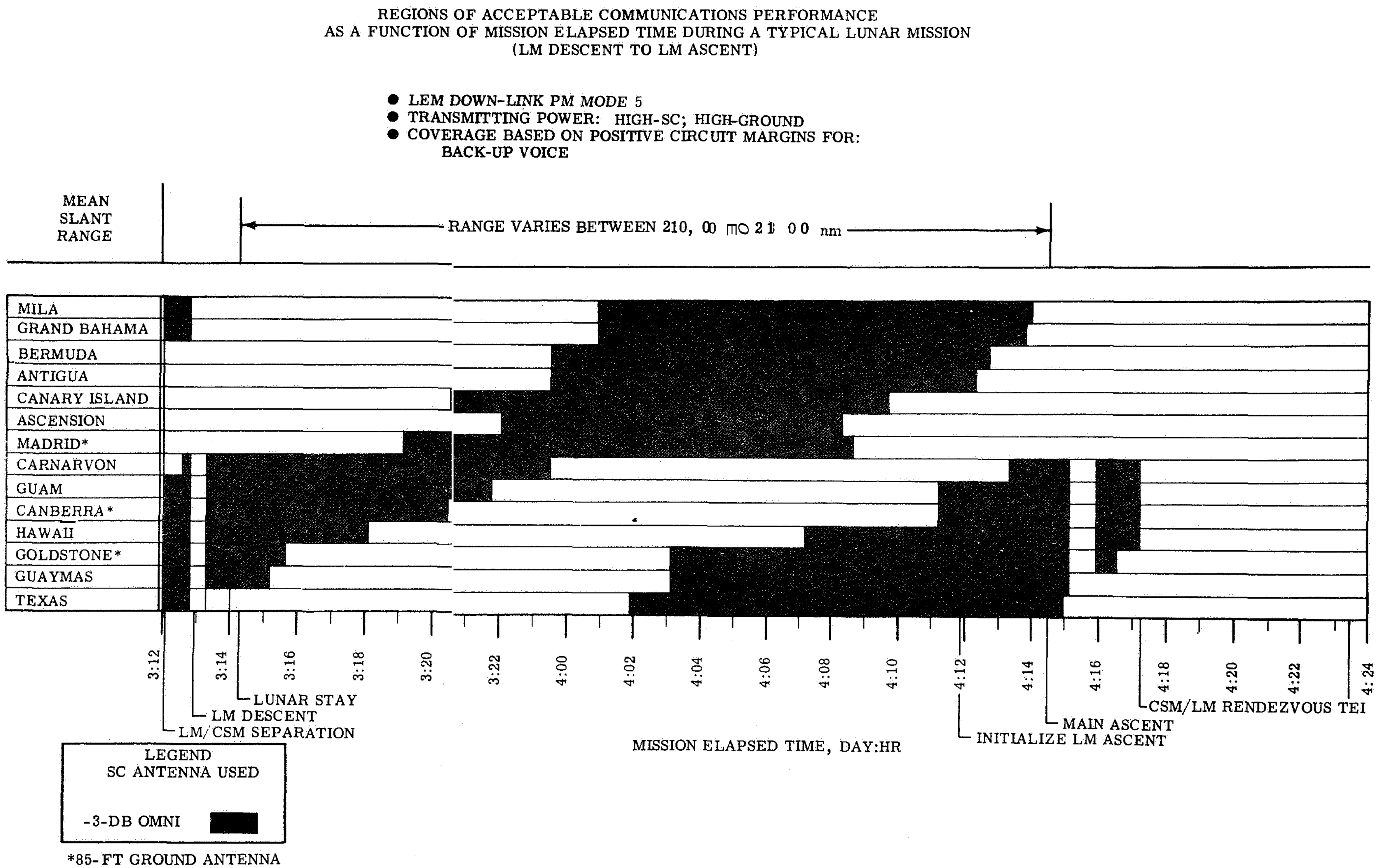


Figure 3-44. LM Mode 5 Station Coverage; Nominal Case, Lunar Stay

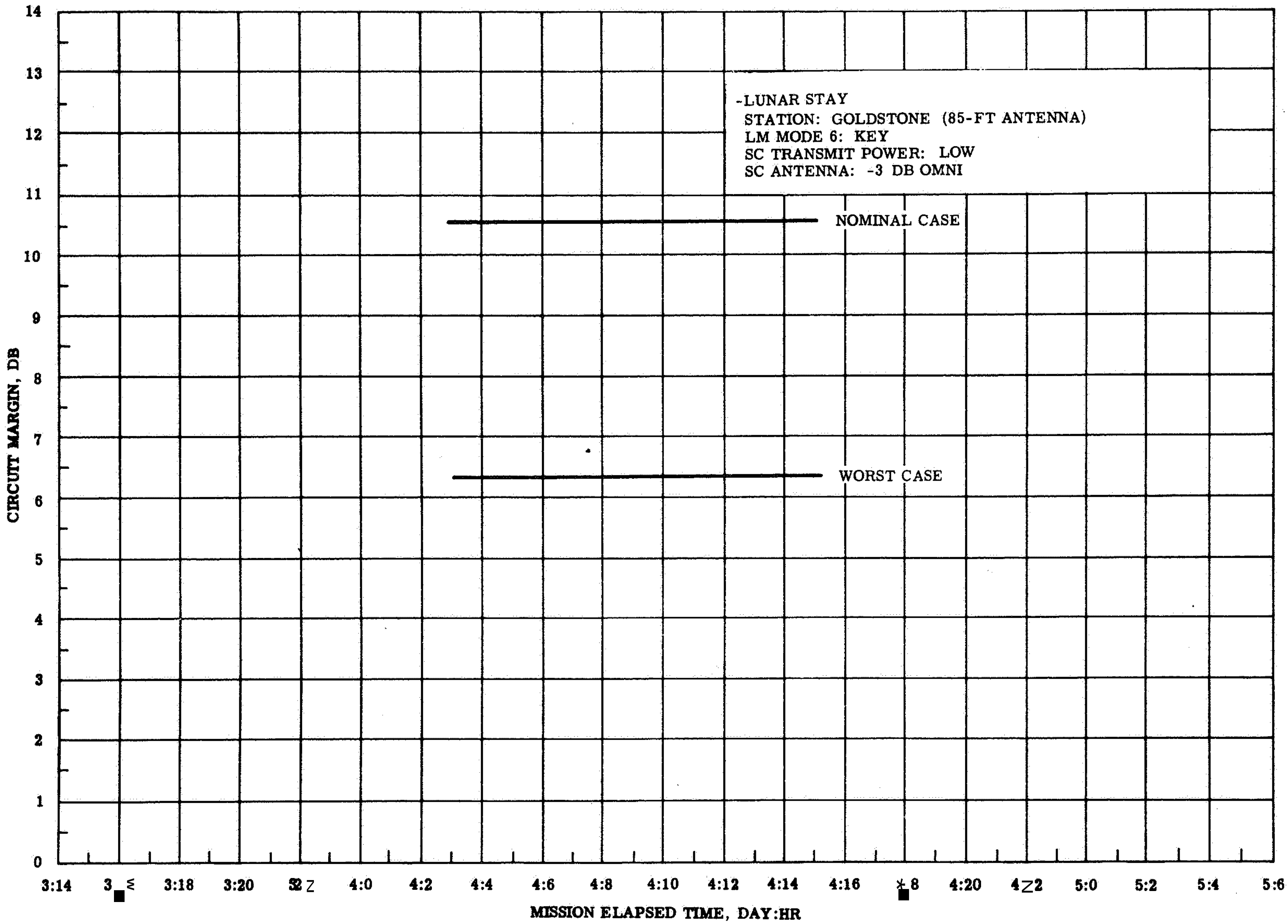


Figure 3-45. LM Mode 6 Circuit Margin Plot; Nominal and Worst Cases, Lunar Stay

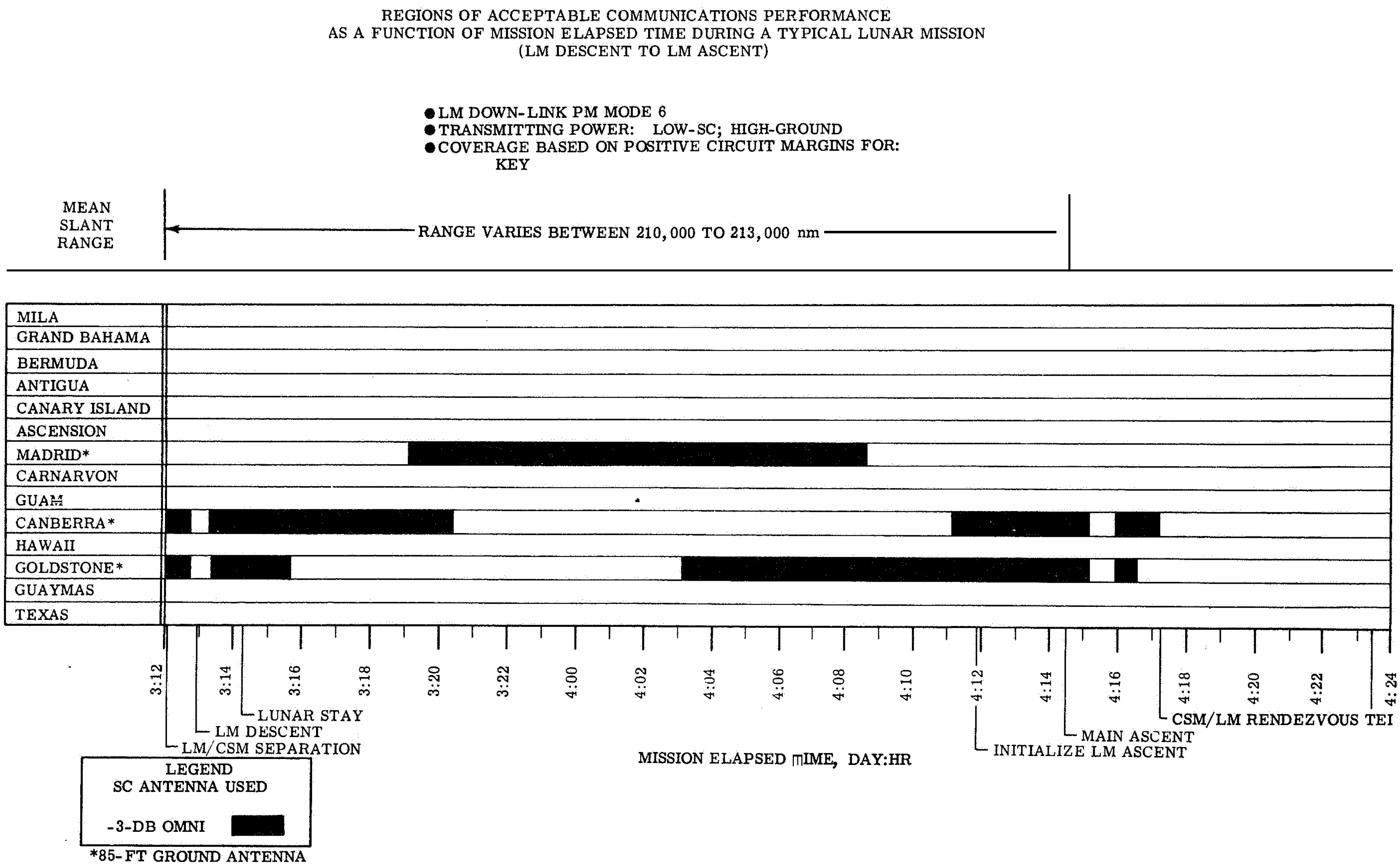


Figure 3-46. LM Mode Station Coverage; Worst Case, Lunar Stay

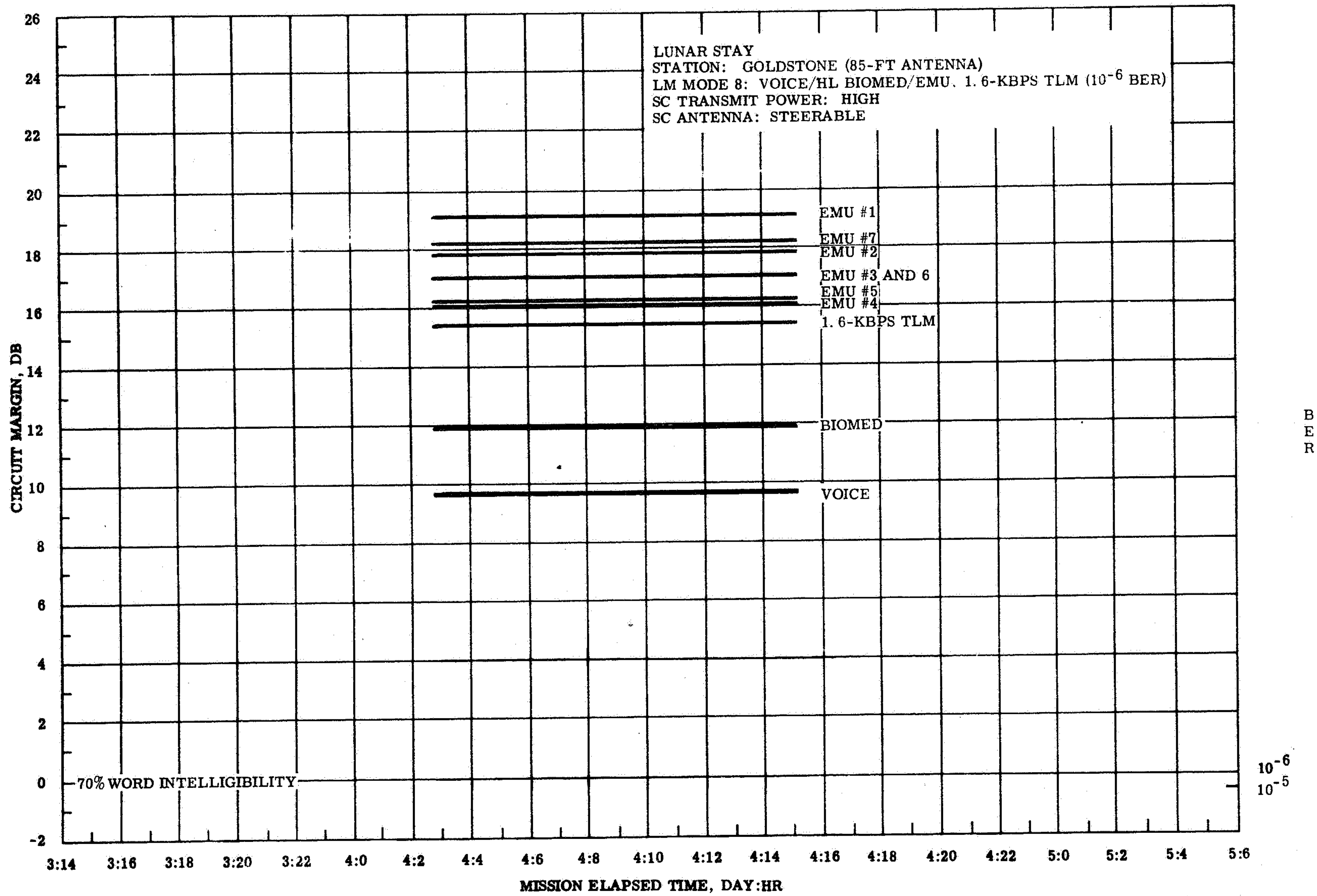


Figure 3-47. LM Special Mode 8 Circuit Margin Plot; Steerable Antenna, Worst Case, Lunar Stay

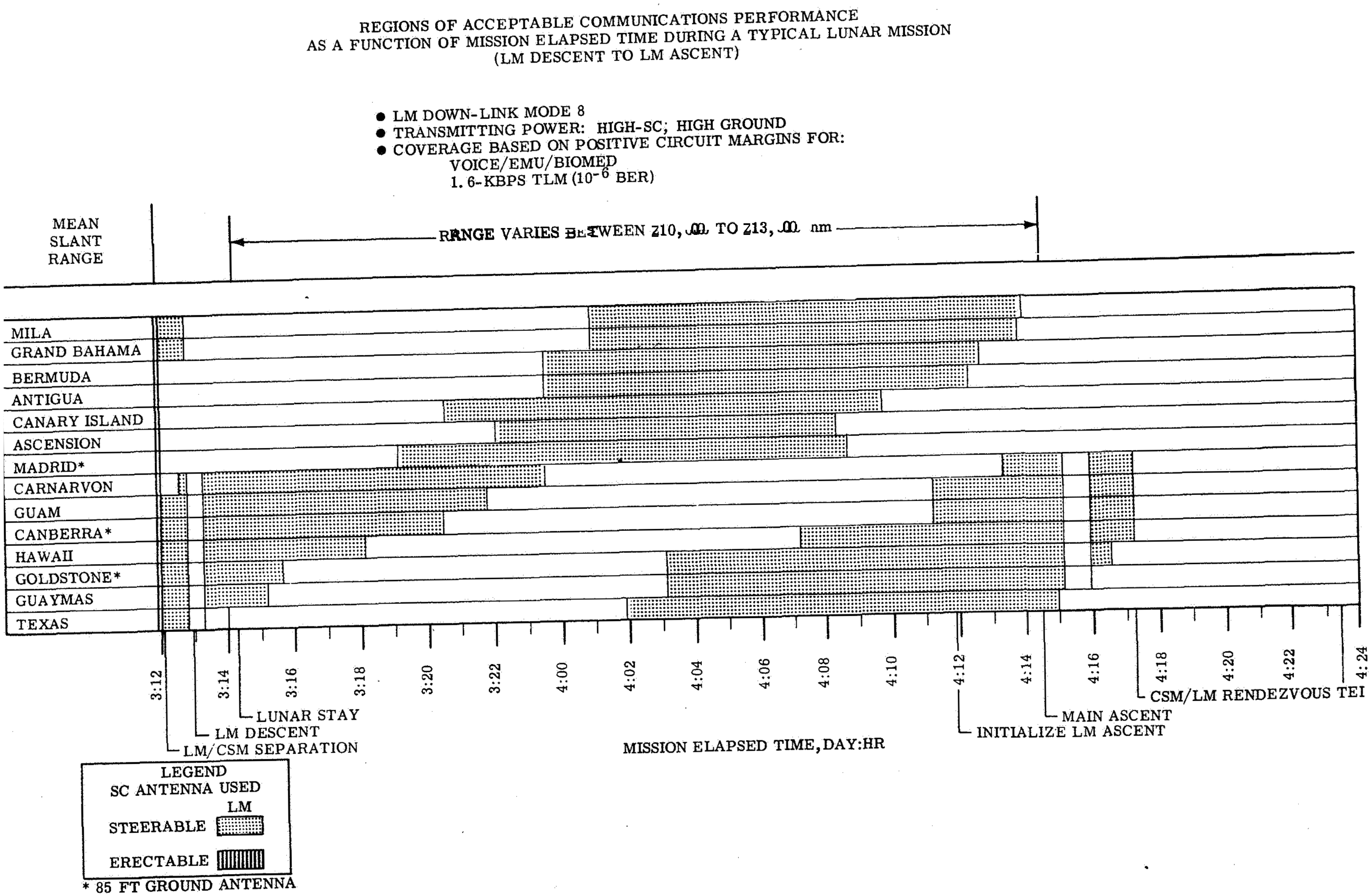


Figure 3-48. LM Special Mode 8 Station Coverage; Worst Case, Descent-Ascent

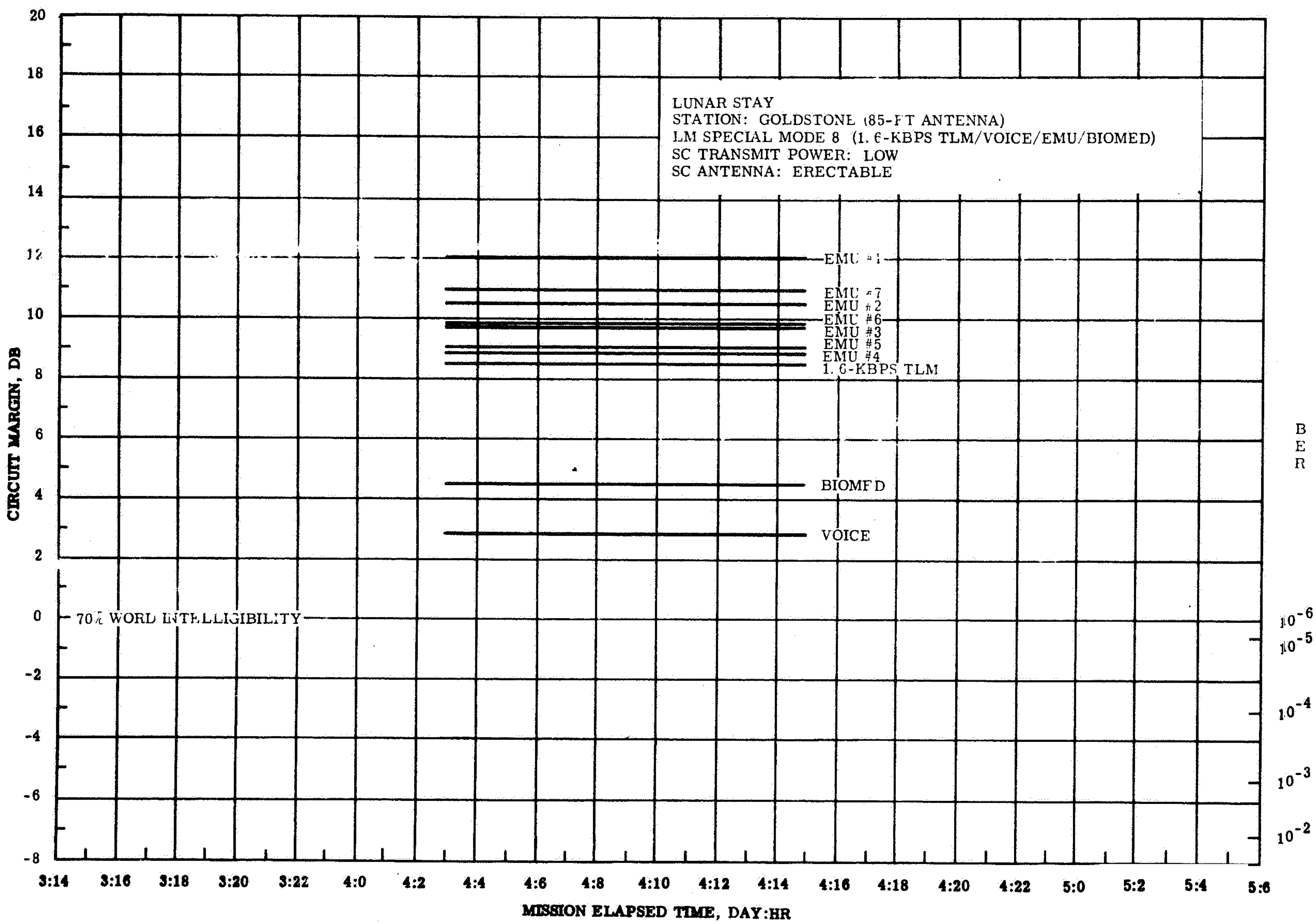


Figure 3-49. LM Special Mode 8 Circuit Margin Plot; Worst Case, Lunar Stay

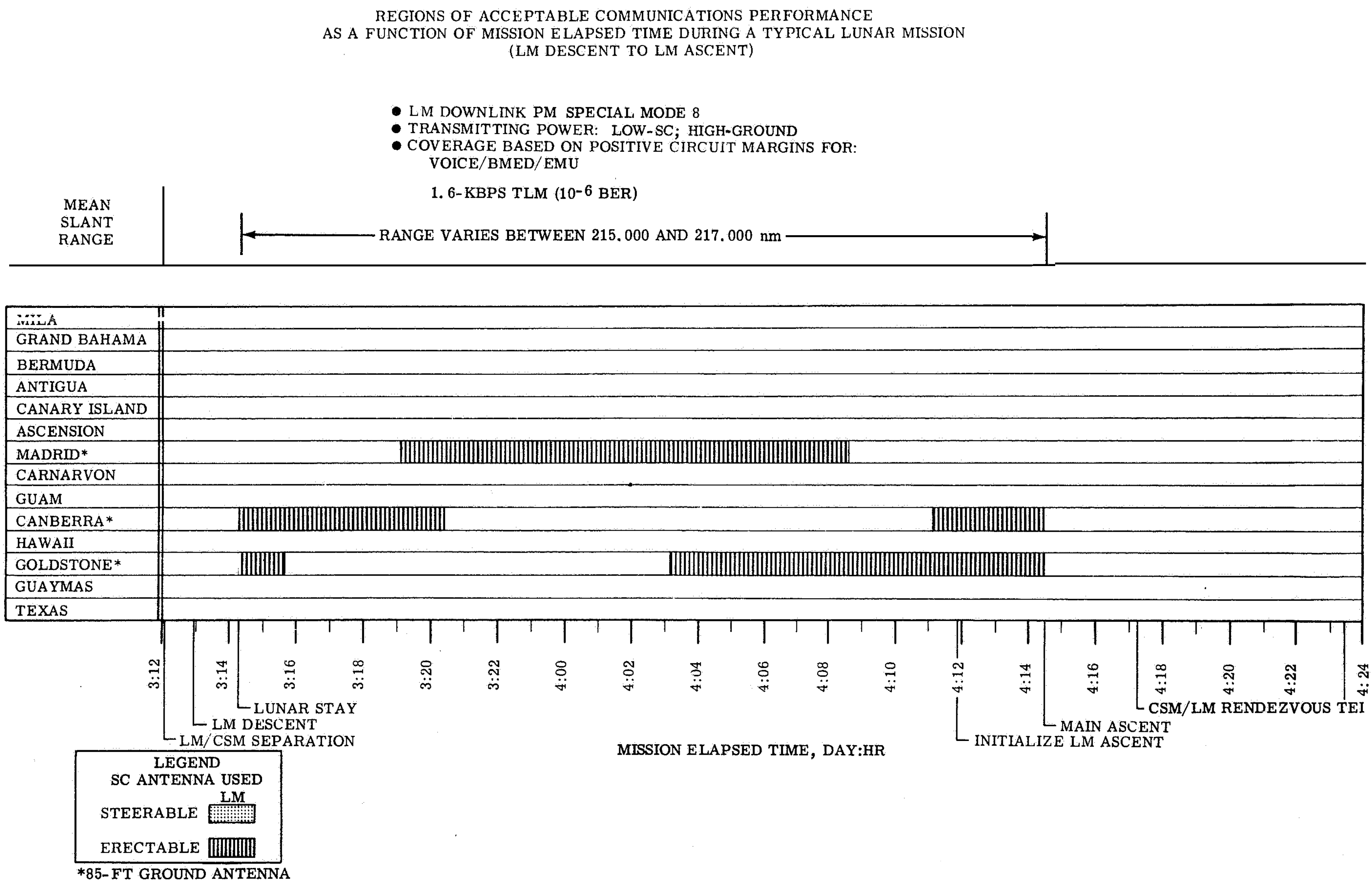


Figure 3-50. LM Special Mode 8 Station Coverage; Worst Case, Lunar Stay

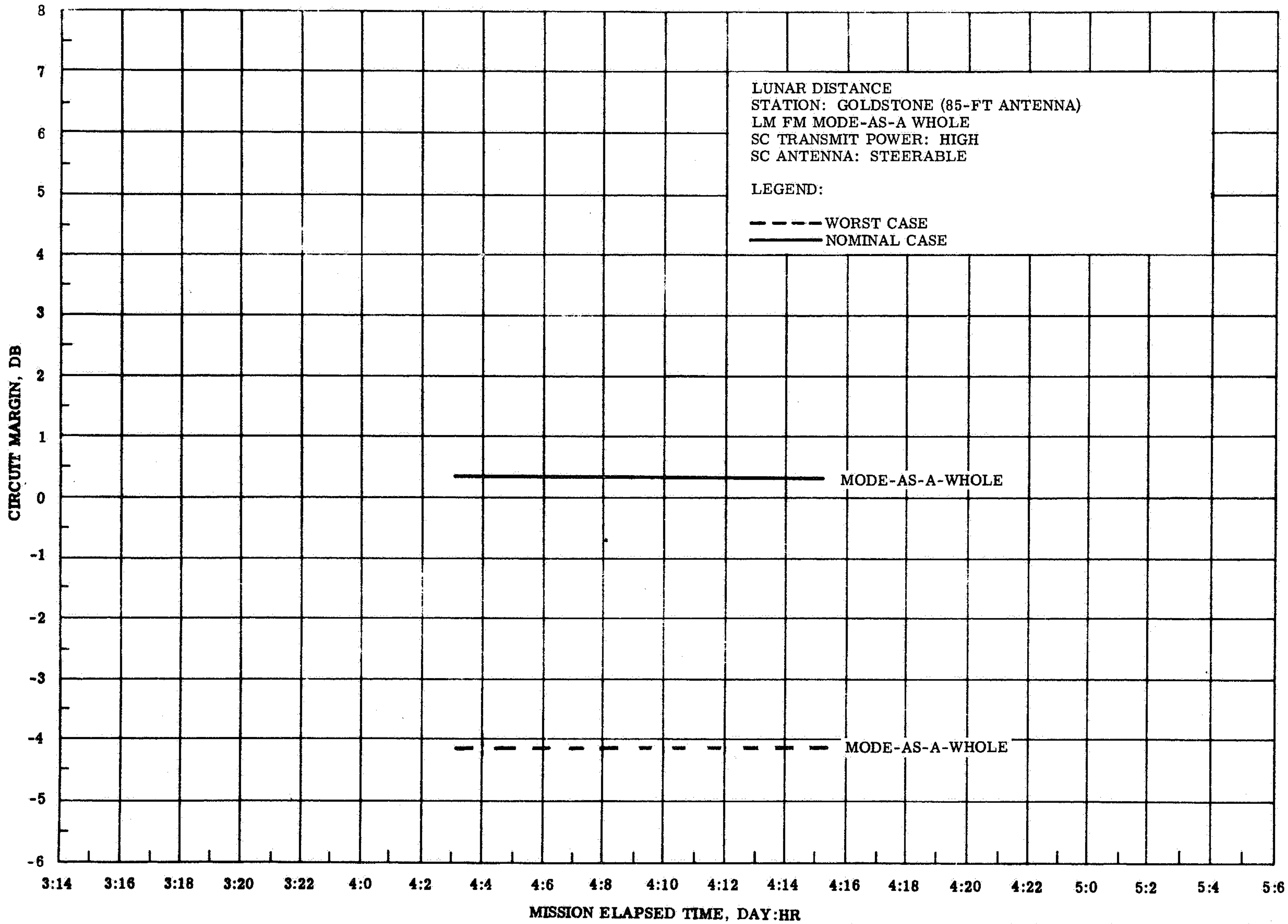
As in the case of the CSM FM modes, the LM FM circuit margins are calculated using the mode-as-a-whole criteria. The detailed discussion in Appendix C applies also to the LM FM modes.

Figure 3-51 is a plot of the nominal and worst case mode-as-a-whole margins for LM FM modes with the steerable antenna. Note that the worst case margin is approximately 4db negative. Figure 3-52 depicts the mode-as-a-whole margin using the erectable antenna. In this case, both the nominal and worst case margins are positive. The station coverage for the LM FM modes is shown in figure 3-53.

TABLE 3-7

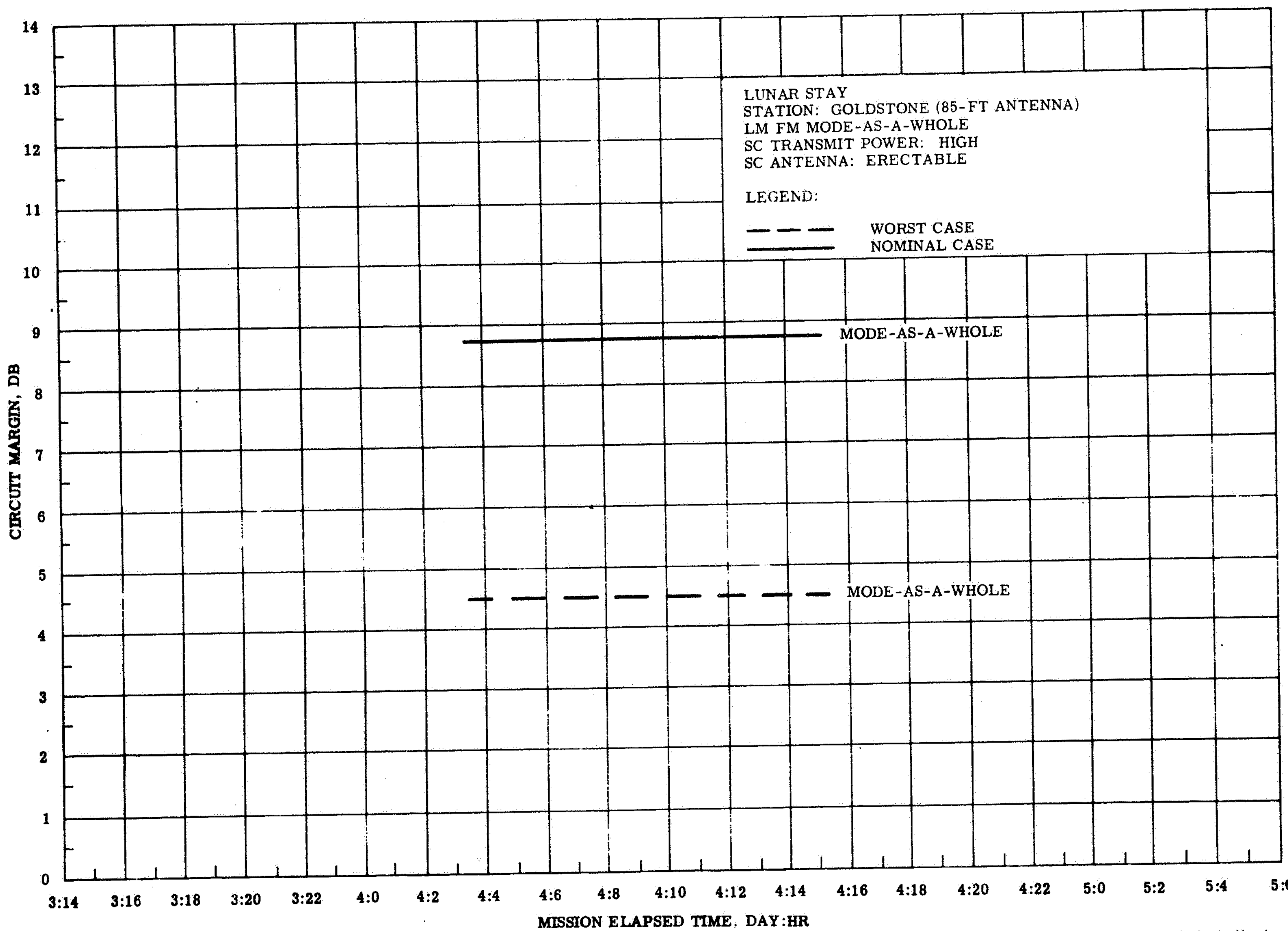
LM FM MODES AND ANTENNA/POWER CONFIGURATIONS

Mode	Service(s)	Antenna		Transmit Power		Criteria
		SC	MSFN	SC	MSFN	
LM FM Mode 3-A	Voice/EMU/ HL Biomed 1.6Kbps TLM	Steerable Erectable	$5-foot	High	High	Mode-as-a-whole 8.0db in a 4MHz BW
LM FM Mode 9-B	Voice/EMU/ HL Biomed 51.2Kbps TLM	Steerable Erectable	85-foot	High	High	Same as 9-A
LM FM Mode 10-A	TV Voice/EMU/ HL Biomed 1.6Kbps TLM	Steerable Erectable	85-foot	High	High	Same as 9-A
LM FM Mode 10-B	TV Voice/E MU/ HL Biomed 51.2Kbps TLM	Steerable Erectable	85-foot	High	High	Same as 9-A



Note: Experimental data indicates that the 8.0db mode-as-a-whole criterion is not adequate for all FM modes. (See Appendix C.)

Figure 3-51. LM FM Mode-As-A-Whole Circuit Margin Plot, Steerable Antenna; Nominal and Worst Cases, Lunar Distance



Note: Experimental data indicates that the 8.0db mode-as-a-whole criterion is not adequate for all FM modes. (See Appendix C.)

Figure 3-52. LM FM Mode-As-A-Whole Circuit Margin Plot, Erectable Antenna; Nominal and Worst Cases, Lunar Stay

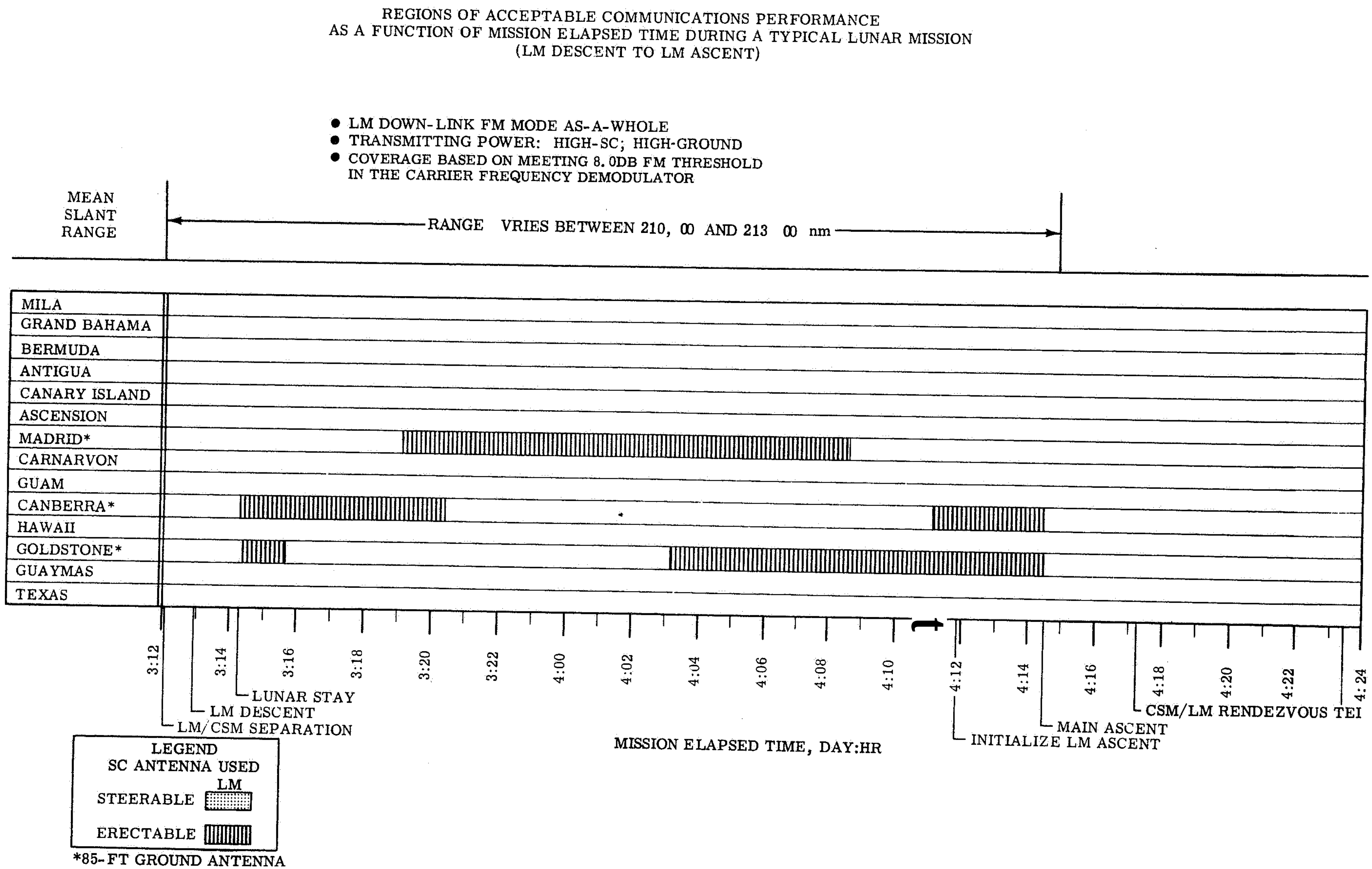


Figure 3-53. LM FM Mode-As-A-Whole Station Coverage; Worst Case, Lunar Stay

4.0 Up-Link Modes Circuit Margin Analysis

Consideration of the up-link performance for the typical lunar mission is limited to a brief discussion of the system capability and a tabulation of the circuit margins for each up-link mode at lunar distance. The large RF output power on the up-link results in signal levels at lunar distance sufficient to provide positive circuit margins in all cases, except in up-link CSM mode 6 when using the SC omni antenna. However, since the only down-link PRN modes (7 and 9) which can be used with the omni antenna have negative marginswith subcarriers on the up-link, operation of up-link mode 6 with the omni antenna is not feasible. Thus, barring a catastrophic failure of the SC USB communication equipment, satisfactory performance of the required up-link functions will be achieved at all times during the mission.

4.1 CSM Up-Link Margins

Table 4-1 is a tabulation of the up-link mode circuit margins for the CSM USB system. The circuit margins listed for the various combinations are based on parameters for an 85-foot MSFN station utilizing high-power output. The margins are calculated for a slant range of 215,000 nm, using worst case tolerances.

TABLE 4-1

CSM UP-LINK CIRCUIT MARGINS

Mode	Service	Circuit Margin (nearest db)	
		CSM High-Gain Antenna	CSM Odb Omni Antenna
1	PRN Ranging*	Not defined	Not defined
2	Voice	30	8
	[illegible]	30	8
4	PRN* Voice	 10	 4
5	PRN* Up-Data	Not defined 10	Not defined 4
6	PRN* Voice Up-Data	 7 4	 2 -1
7	Voice Up-Data	25 25	4 4

For Modes 2, 3, 7, and 8, a reduction in up-link power to 2 Kw and the use of a 30-foot MSFN station yields positive circuit margins when the SC high-gain antenna is used. Although it is not apparent from the magnitude of the margins shown, the same statements are true for Modes 4, 5, and 6. PRN range code interference in the voice and up-data channels limits the performance of these channels to approximately the level indicated by the circuit margins for the SC high-gain antenna in table 4-1. For example, the voice circuit margin for Mode 4 using a zero-db omni antenna gain at a slant range of 1000 nm is 10.4db. At a slant range of 220,000 nm, using a 27db SC antenna gain, the circuit margin is 10.3db. The total received power at the larger range decreases due to a 46.8db increase in space loss. The antenna gain has increased by 27db resulting in a net loss of 19.8db in total received power. Thus, despite this large loss in available power, the circuit margin has decreased by only 0.1db.

Table 4-1 shows that all up-link modes, with the exception of mode 6 perform satisfactorily on the SC omni antenna if an 85-foot MSFN station is used.

4.2 LM Up-Link Margins

Table 4-2 gives the LM up-link circuit margins. These margins are calculated for an 85-foot station using high power output at 215,000 nm with worst case tolerances. Expansion of the LM USB system to include an up-data capability is planned. Due to the -3db omni antenna gain anddegradation in the SC wide-band phase detector, the LM up-link is constrained to receiving either voice or up-data, i.e., simultaneous up-data and voice will not be possible at lunar distance when' the omni antenna is used.

TABLE 4-2

LM UP-LINK CIRCUIT MARGINS

Mode	Service	Circuit Margin (nearest db) LM -3db Omni Antenna
1	PRN Ranging*	Not defined
2	Voice	7
3	PRN*	Not defined
	Voice	4

*Ranging channel performance is based on a two-way link.

APPENDIX A

SYSTEM PARAMETERS VALUES FOR CIRCUIT MARGIN CALCULATION

The listings in this appendix are a compilation of all the Unified S-Band System parameters used in the calculation of circuit margins. The values listed, except where noted, correspond to those appearing in the applicable Performance Interface (P&I) Specifications or related Specification Change Notice.

Table A-1 lists the parameter values for the CSM system. Table A-2 lists the LM system parameters.

TABLE A-1 (a)

CSM System Parameters (Up-Link)

Up-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
MSFN Transmit Power (High)	10,000	-500	+500	Watts
MSFN Transmit Power (Low)	2)000	-100	+100	Watts
30 Foot Antenna Transmit Gain	43.0	-0.0	+0. 25	db
85 Foot Antenna Transmit Gain	52.0	-2.0	+0. 0	db
Up-Link Carrier Frequency	2106.406	0.0	0.0	MHz
SC Antenna Receiver Gain				
Omni (Specified)	0.0	0.0	0.0	db
High-Gain (WBW)	3.8	0.0	0.0	db
High-Gain (MBW)	22.8	0.0	0.0	db
High-Gain (NBW)	23.3	.0. 0	0.0	db

TABLE **A-1** (a) (Continued)

Up-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
SC Receive Circuit Losses				
Omni Antenna	-6.2	0.0	0.0	db
High-Gain Antenna	-7.0	0.0	0.0	db
SC High-Gain Antenna Pointing Loss	-0.20	0.0	0.0	db
Polarization Loss	0.0	0.0	0.0	db
SC Receiver				
IF Noise Bandwidth	4.6	0.3	0.0	MHz
Video Noise Bandwidth	1.7	0.0	0.0	MHz
Carrier Loop Noise Bandwidth	800.0	0.0	0.0	Hz
Voice Subcarrier Predetection Noise Bandwidth	22.0	2. 2	1. 1	KHz
Updata Predetection Noise Bandwidth	22.0	2.2	1. 1	KHZ
Required Signal-to-Noise Ratios				
Carrier	12.0	0.0	0.0	db
Voice	10.0	0.0	0.0	db
updata	10.0	0.0	0.0	db
Up-Link Modulation Indices				
Mode 1 PRN Ranging	1.34	0.0	0.0	rad
Mode 2 Voice	1.85	0. 0	0.0	rad

TABLE A-1 (a) (Continued)

Up-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
Up-Link Modulation Indices (Continued)				
Mode 3 Updata	1.85	0.0	0.0	rad
Mode 4 PRN Ranging	0.80	0.0	0.0	rad
Voice	1.85	0.0	0.0	rad
Mode 5 PRN Ranging	0.80	0.0	0.0	rad
Updata	1.85	0.0	0.0	rad
Mode 6 PRN Ranging	0.50	0.0	0.0	rad
Voice	1.00	0.0	0.0	rad
Updata	0.76	0.0	0.0	rad
Mode 7 Voice	1.10	0.0	0.0	rad
Updata	1.10	0.0	0.0	rad
Mode 8 Backup Voice	1.85	0.0	0.0	rad
System Noise Temperature Where Pc = received carrier power in watts	$5800 + 2.75 \times 10^{13}$ Pc			^{o}K

TABLE A-1 (b)

CSM SYSTEM PARAMETERS (DOWN-LINK)

Down-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
SC PM Mode Transmit Power				
High	11.2	0.0	0.0	Watts
Low	2.8	0.0	0.0	Watts
Bypass	0.125	0.0	0.0	Watts
SC FM Transmit Power	10.0	0.0	0.0	Watts
85 Foot Antenna Receive Gain	53.0	-2.5	0.0	db
30 Foot Antenna Receive Gain	44.0	0.0	0.25.	db
SC Antenna Transmit Gain				
Omni	Measured Pattern Data			
High-Gain (WBW)	9.2	0.0	0.0	db
High-Gain (MBW)	20.8	0.0	0.0	db
High-Gain (NBW)	27.0	0.0	0.0	db
SC Transmit Circuit Losses				
Omni Antenna	-6.2	0.0	0.0	db
High-Gain Antenna	-7.0	-0.7	0.0	db
Down-Link Carrier Frequency (PM)	2287.5	0.0	0.0	MHz
(FM)	2272.5	0.0	0.0	MHz
Ranging Channel Gain Constant	0.615	0.0	0.0	
MSFN PM Receiver				
IF Noise Bandwidth	4.80	0.50	-0.50	MHz

TABLE A-1 (b) (Continued)

Down-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
MSFN PM Receiver (Continued)				
Carrier Loop Noise Bandwidth				
Wide	700	140	0.0	Hz
Medium	200	0.0	-40.0	Hz
Narrow	50	0.0	-10.0	Hz
PRN Ranging Noise Bandwidth	1.0	0.0	0.0	Hz
Predetection Noise Band-width				
Voice/Biomed	42.0	6.0	0.0	KHZ
51.2 Kbps TLM	180.0	18.0	-18.0	KHz
1.6 Kbps TLM	7.25	0.725	-0.725	KHZ
Emergency Key	1.35	0.135	-0.135	KHZ
Backup Voice	2.84	0.284	-0.284	KHZ
MSFN FM Receiver				
Predetection Noise Band-width				
Unfiltered	16.8	0.0	-7.2	MHz
Medium	4.0	0.8	0.0	MHz
Narrow	1.0	0.2	0.0	MHz

TABLE A-1 (b) (Continued)

Down-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
MSFN FM Receiver (Continued)				
Loop Noise Bandwidth				
Wide	11.0	1.1	-1.1	MHz
Narrow	4.0	0.4	-0.4	MHz
Required Predetection Signal-to-Noise Ratios				
Carrier	12.0*	0.0	0.0	db
PRN Ranging	32.0	0.0	0.0	db
Voice/Biomed	8.0	0.0	0.0	db
51.2 Kbps TLM	8.5	0.0	0.0	db
1.6 Kbps TLM	7.4	0.0	0.0	db
Emergency Key	-10.5	0.0	-4.0	db
Backup Voice	4.0	0.0	0.0	db
FM (Mode-as-a-whole)	8.0	0.0	0.0	db
Peak-to-RMS Value				
PM Backup Voice (24 db peak clipping)	1.52	0.0	0.0	
Downlink Modulation Indices				
Mode 1 Voice/Biomed	0.70	0.0	0.0	rad
51.2 Kbps TLM	1.20	0.0	0.0	rad
Mode 2 PRN Ranging				
Voice/Biomed	0.70	0.0	0.0	rad
51.2 Kbps TLM	1.20	0.0	0.0	rad

*6db for the emergency key mode (Mode 6)

TABLE A-1 (b) (Continued)

Down-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
Down-Link Modulation Indices (Continued)				
Mode 3 PRN Ranging				
Voice/Biomed	1.20	0.0	0.0	rad
1.6 Kbps TLM	0.70	0.0	0.0	rad
Mode 4 Voice/Biomed	1.20	0.0	0.0	rad
1.6 Kbps TLM	0.70	0.0	0.0	rad
Mode 5 1.6 Kbps TLM	1.60	0.0	0.0	rad
Mode 6 Emergency Key	1.00	0.0	0.0	
Mode 7 PRN Ranging				
Mode 8 BU Voice	0.70	0.0	0.0	rad
1.6 Kbps TLM	1.20	0.0	0.0	rad
Mode 9 PRN Ranging				
1.6 Kbps TLM	1.60	0.0	0.0	rad
Mode 10 BU Voice	1.20	0.0	0.0	rad
System Noise Temperature				^oK
85'-Antenna				
Quiet Sky	$96 + 3.05 \times 10^{15}$ Pc			
Moon at Zenith	$209 + 3.05 \times 10^{15}$ Pc			
30'-Antenna (cooled)				
Quiet Sky	$96 + 3.05 \times 10^{15}$ Pc			
Moon at Zenith	$135 + 3.05 \times 10^{15}$ Pc			

TABLE A-1 (b) (Continued)

Down-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
System Noise Temperature (Continued)				°K
30' Antenna (Uncooled)				
Quiet Sky	$250 + 3.05 \times 10^{15}$ Pc			
Moon at Zenith	$289 + 3.05 \times 10^{15}$ Pc			
Where Pc = Received Carrier Power in Watts				

TABLE A-2 (a)

LM SYSTEM PARAMETERS (UP-LINK)

Up-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
See Table A-1 (a) for MSFN Transmit Power and Antenna Gain				
Uplink Carrier Frequency	2101.802	0.0	0.0	MHz
Polarization Loss				
Omni Antenna	-0.10	0.0	0.0	db
Steerable Antenna	-0.10	0.0	0.0	db
Erectable Antenna	-0.10	0.0	0.0	db
Pointing Loss				
Steerable Antenna	-0.5	0.0	0.1	db
Erectable Antenna	-2.0	0.0	0.0	db

TABLE A-2 (a) (Continued)

Up-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
Uplink Carrier Fequency (Continued)				
Receive Circuit Losses				
Omni Antenna	-5.7	-0.50	2.00	db
Steerable Antenna	-5.9	-0.50	2.00	db
Erectable Antenna	-9.8	-0.50	2.00	db
SC Receive Antenna Gain				
Omni (Specified)	-3.0	0.0	0.0	db
Steerable	16.5	0.0	3.0	db
Erectable	33.2	0.0	0.0	db
SC Receiver				
IF Noise Bandwidth	4.8	0.3	-0.5	MHz
Video Noise Bandwidth	1.8	0.18	-0.3	MHZ
Carrier Loop Noise Bandwidth	1.1	.4	-.4	KHz
Voice Subcarrier Pre-detection Noise Bandwidth	22.0	2.20	-1.00	KHz
Required Predetection SNR				
Carrier	12.0	0.0	0.0	db
Voice	10.0	0.0	0.0	db

TABLE A-2 (a) (Continued)

Up-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
Uplink Modulation Indices				
Mode 1 PRN Ranging	1.34	-0.130	0.130	rad
Mode 2 Voice	1.85	-0.180	0.180	rad
Mode 3 PRN Ranging	0.80	0.0	0.0	rad
Voice	1.85	0.0	0.0	rad
System Noise Temperature	$3360 + 1.26 \times 10^{14}$ Pc			^{o}K
Where Pc = Received Carrier Power in Watts				

TABLE A-2 (b)

Down-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
See Table A-1 for MSFN Antenna Gains				
SC Transmit Antenna Gain				
Qmni (Specified)	-3.0	0.0	0.0	db
Steerable	20.5	-0.3	0.0	db
Erectable	34.0	0.0	0.0	db
Pointing and Polarization Losses	Same as for up-link			
SC Transmit Circuit Losses				
Qmni			2.0	db

TABLE **A-2** (b) (Continued)

Down-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
SC Transmit Circuit Losses (Continued)				
Steerable	-5. 1	-0.5	2.0	db
Erectable	-8.9	-0.5	2.0	db
SC Transmit Power				
High	20.0	-3.0	1. 4	Watts
Low	0.72	0.0	0.28	Watts
Down-Link Frequency	2282.5	0.0	0.0	MHz
Ranging Gain Constant	0.630	0.158	-0. 158	
MSFN Receiver Noise Bandwidths	Are the same as for CSM Down-link (Table A-) with the following additions,			
Additional MSFN Receiver Noise bandwidths required for LM Modes (predetection unless noted otherwise)				
Baseband				
Voice (postdetection)	4.0	0.40	0.40	KHz
HL Biomed	2.176	2. 17	-2.17	KHZ
EMUNo. 1	400	0.40	-0.4	Hz
2	540	0.54	-0.54	Hz
3	680	0. 68	-0.68	Hz

TABLE A-2 (b) (Continued)

Down-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
Additional MSFN Receiver Noise Bandwidths required for LM Modes (Continued)				
EMU No. 4	820	0.82	-0.82	Hz
5	768	0.77	-0.77	Hz
6	660	0.66	-0.66	Hz
7	496	0.50	-0.50	Hz
Additional Required SNR for LM Baseband Modes				
Voice	14.0	0.0	0.0	db
HL Biomed	5.0	0.0	0.0	db
EMU Nos. 1-7	5.0	0.0	0.0	db
Peak-to-RMS Ratio				
BU Voice (24 db peak clipping referred to a 3-KHz tone with 6 db/octave preemphasis)	1.52	0.0	0.0	
Baseband Voice (0 db peak clipping)	5.31	0.0	0.0	rad
Downlink Modulation Indices				
Mode 1 Voice/HL Biomed	0.90	0.0	0.0	rad
51.2 Kbps TLM	1.30	0.0	0.0	rad
Mode 2 PRN Ranging				
Voice/HL Biomed	0.90	0.0	0.0	rad

*Tolerances on modulation indices are included in the LM Performance and Interface Specification but are not used in the circuit margin calculations.

TABLE A-2 (b) (Continued)

Down-Link Parameter	Nominal Value	Tolerance Worst	Tolerance Best	Units
Downlink Modulation Indices (Continued)				
51.2 Kbps TLM	1.30	0.0	0.0	rad
Mode 31.3 Kbps TLM	1.30	-0.19	0.27	rad
Mode 4 BU Voice	0.80	0.0	0.0	rad
1.6 Kbps TLM	1.30	0.0	0.0	rad
Mode 5 BU Voice	0.80	-0.20	0.20	rad
Mode 6 Emergency Key	1.40	-0.22	0.28	rad
Mode 7 Voice/HL Eiomed	1.30	0.0	0.0	rad
1.6 Kbps TLM	0.90	0.0	0.0	rad
Mode 8 Voice	0.73	0.0	0.0	rad
HL Biomed	0.20	0.0	0.0	rad
*l. 6 Kbps TLM	0.70	0.0	0.0	rad
EMU 1-7	0.20	0.0	0.0	rad
System Noise Temperature	See Table A-1 (b)			

*A request has been made to officially change to this value.

APPENDIX B

SAMPLE CALCULATIONS

This appendix contains sample circuit margin calculations for the Apollo USB System. No attempt is made here to justify the mathematical equations used in the calculations. For a detailed discussion of the USB math model and the use of its equations, the reader is referred to two reports by the Systems Analysis Branch of the Information Systems Division, MSC. (References 1 and 2)

The sample calculation below is for the carrier and information channels of CSM up-link Mode 6 (PRN, Voice, Up-Data). Worst case conditions are assumed for an 85-foot MSFN station with high power output and the spacecraft omni antenna at 215,000 nm.

	Step	Value	Units
(1)	MSFN Transmit Power	39.8	dbw
(2)	MSFN Transmit Antenna Gain (includes pointing and circuit loss)	50.0	db
(3)	Space Loss (f = 2106 MHz, R = 215,000 nm)	-210.9	db
(4)	Polarization Loss	0.0	db
(5)	CSM Omni Antenna Gain	0.0	db
(6)	CSM Receive Circuit Loss	-6.2	db
(7)	CSM Received Total Power (sum through 1-6)	-127.3	dbw

Step	Carrier	Channel Voice	Up-Data	Units
(8) Modulation Loss	-4.8	-6.6	-9.5	db
(9) Channel Power (7 + 8)	-132.1	-133.9	-136.8	dbw
(10) Noise Spectral Density	-191.0	-191.0	-191.0	dbw
(11) Noise Bandwidth	29.1	43.8	43.8	db
(12) Channel Noise Power (10 + 11)	-161.9	-147.2	-147.2	dbw
(13) Total Noise + PRN Code Interference Power	-161.9	-145.5	-145.5	dbw
(14) Channel SNR (9 - 13)	29.8	11.6	8.7	db
(15) Required SNR	12.0	10.0	10.0	db
(16) Circuit Margin (14 - 15)	17.8	1.6	-1.3	db

Calculation of the down-link mode circuit margins is similar to that for the up-link. Calculations are shown below for CSM down-link Mode 2 (Carrier, PRN, Voice, and 51.2Kbps TLM) assuming PRN and two subcarriers on the up-link (up-link Mode 6). Worst case conditions are assumed for an 85-foot MSFN station using high power output and the spacecraft high gain NBW antenna at 215,000 nm. The spacecraft SNR used in determining the modulation loss (step 9) is calculated with the SC High Gain NBW antenna.

Step	Value	Units
(1) SC Transmit Power	10.5	dbw
(2) SC Transmit Antenna Gain	27.0	db
(3) SC Transmit Circuit Loss	-7.7	db
(4) SC Antenna Pointing Loss	-0.2	db
(5) Polarization Loss	0.0	db

Step		Value	Units
(6)	Space Loss (f = 2287.5 MHz, R = 215,000 nm)	-211.6	db
(7)	MSFN Receive Antenna Gain (includes pointing and circuit losses)	50.5	db
(8)	MSFN Total Received Power (sum 1 through 7)	-131.5	dbw

		Carrier	PRN	Channel Voice	51.2Kbps TLM	
(9)	Modulation Loss (includes loss due to turnaround noise and up-link sub-carriers)	-5.3	-19.4	-10.8	-4.9	db
(10)	Channel Power (8 + 9)	-136.8	-150.9	-142.3	-136.4	dbw
(11)	Noise Spectral Density	-204.2	-204.2	-204.2	-204.2	dbw
(12)	Channel Noise Band-width	17.0	0.0	46.8	53.0	db
(13)	Channel Noise Power (11 + 12)	-187.2	-204.2	-157.4	-151.2	dbw
(14)	Noise + Interference Power (due to cross modulation products)	---	---	---	-151.2	dbw
(15)	Channel SNR (10 - 13 or 10 - 14)	50.4	53.3	15.1	14.8	db
(16)	Required SNR	12.0	32.0	8.0	8.5	db
(17)	Circuit Margin (15 - 16)	38.4	21.3	7.1	6.3	db

APPENDIX C

A DISCUSSION OF FM MODE-AS-A-WHOLE MARGINS IN TERMS OF OUTPUT PERFORMANCE

Introduction

Requirements for the FM channels in the Apollo USB System have previously been defined in terms of an FM mode-as-a-whole signal-to-noise ratio. A SNR of 8db is required in the effective predetection noise bandwidth of the carrier frequency demodulator. (See figure C-1.) This 8db mode-as-a-whole value is defined as threshold for linear operation of the phase-lock loop discriminators in the MSFN stations. However, slightly positive margins based on the 8db mode requirement do not necessarily ensure satisfactory output performance. In addition, the non-linear region below threshold is of interest because the received FM signal power from the Apollo spacecraft at lunar distance, under worst-case conditions, can cause operation in this region.

The 8db value was assigned early in the Apollo Program, and at that time, presented the most severe constraint. That is, if the SNR_{in} stayed above threshold, the final output requirements would be met or exceeded in each FM output channel. Thus the single predetection requirement would satisfy all FM voice, telemetry, and television postdetection requirements. However, recent evaluations and testings of the FM channels indicate that the 8db requirement will nut be adequate using present MSFN demodulation equipment.

The purpose of this appendix is to investigate the Unified S-Band FM performance and to determine the required signal-to-noise ratios for each FM mode., Experimental data from the Special FM Tests', the LM Gross Tests[4], and the Block II Gross Tests taken in the Electronic Systems Compatibility Laboratory in the Information Systems Division, MSC, have been used to qualify and validate the theoretical results presented here. The threshold requirements are discussed in detail in an FM report[5] to be released shortly. A block diagram of the FM demodulation channels in the MSFN receiver is shown in figure C-1.

The system performance curves presented in this appendix are a result of theoretical analysis and test data evaluation. In most instances test data secured on FM channel performance in the ESCL is degraded from what is predicted theoretically. Thus the expected performance curves are theoretical performance predictions, as obtained by Rice's model[6] for an ideal

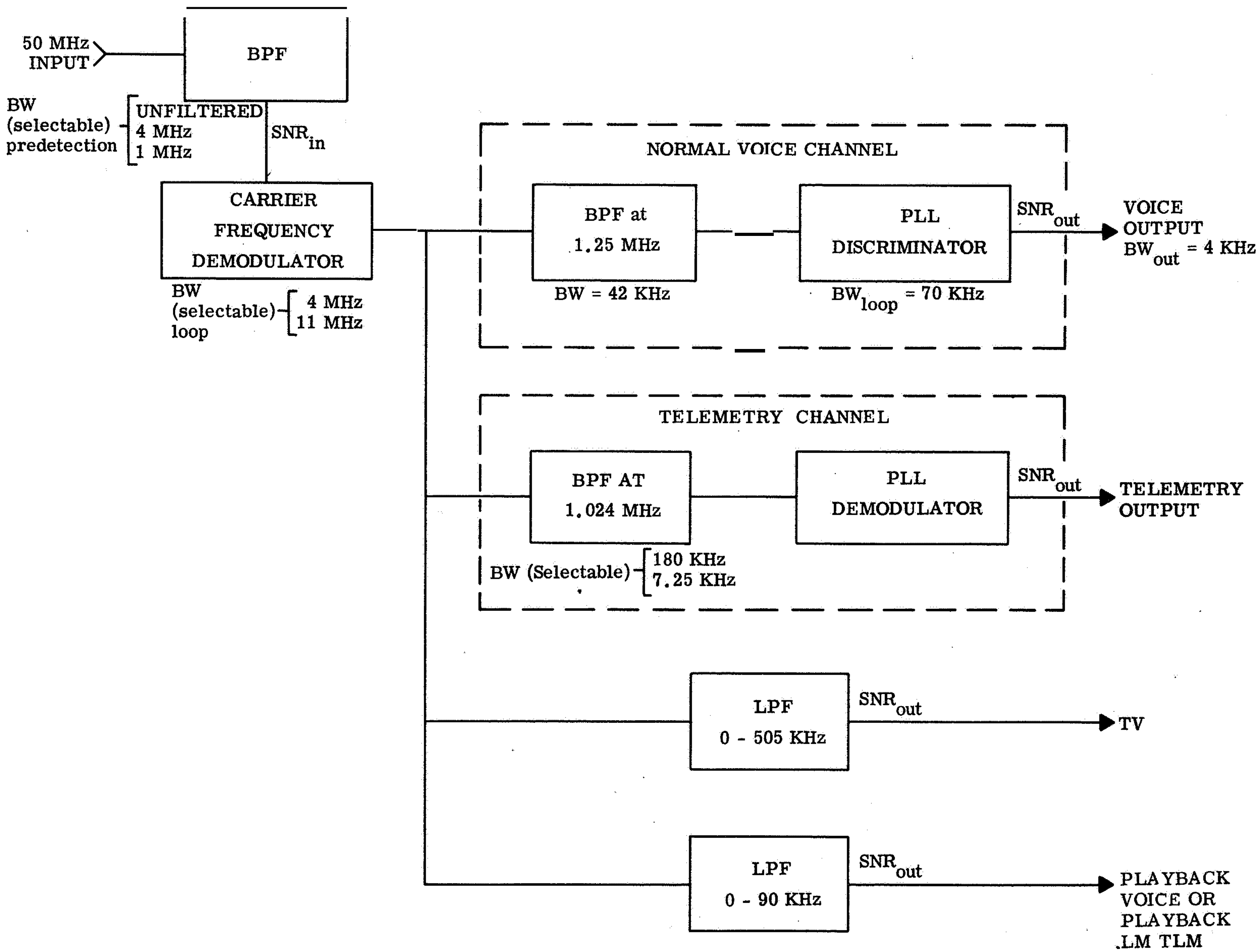


Figure C-1. Block Diagram of FM Demodulation Channels in an MSFN Receiver conventional discriminator, shifted along the horizontal axis by a Δdb factor that represents the mean degradation from theoretical performance observed during ESCL tests. The value of the Δdb shift applied for each transmitted function is given in the summary table (table C-1) at the end of this appendix.

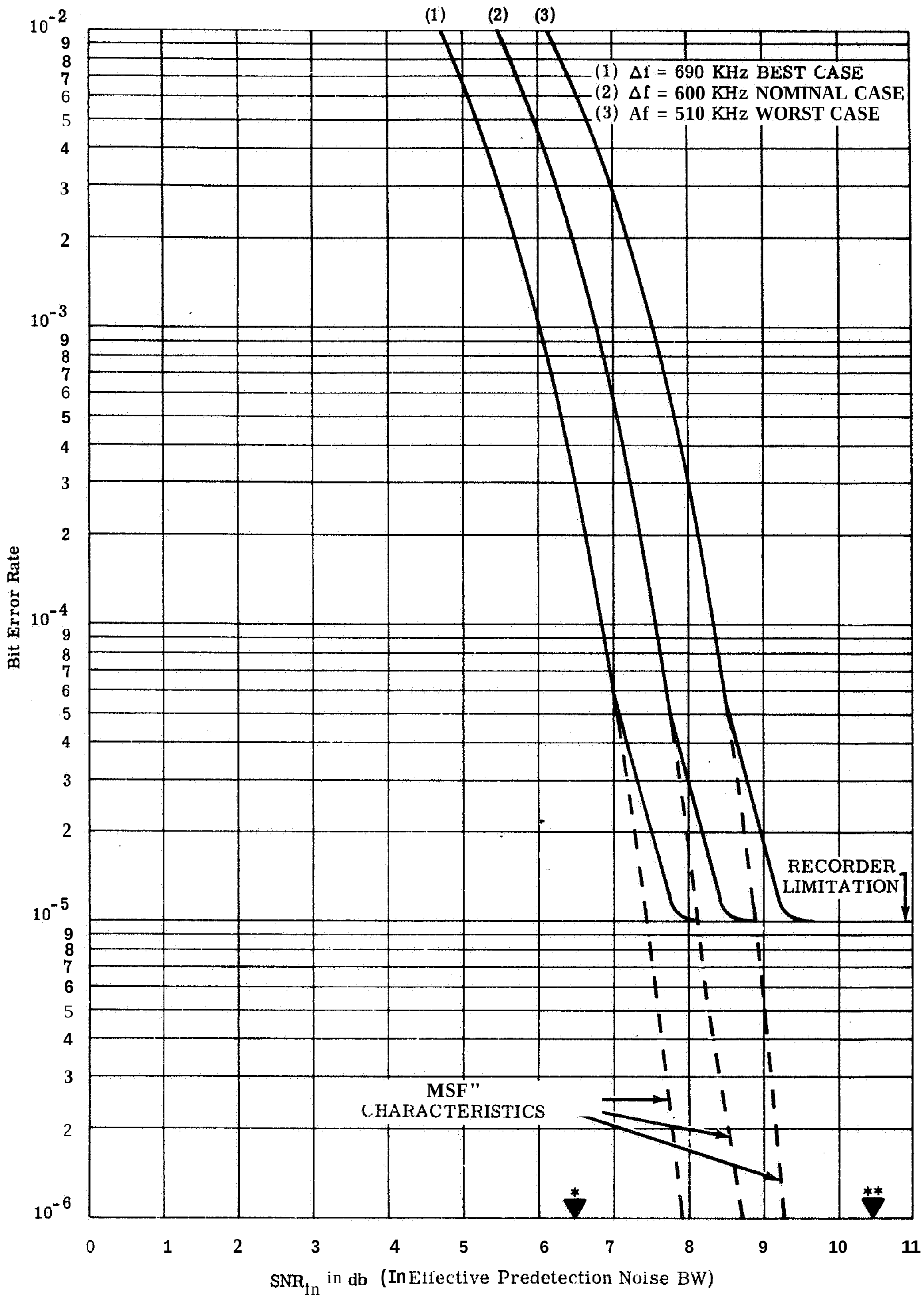
CSM Telemetry

The CSM FM Modes 1 and 2 have playback CSM telemetry at 1:1 and 32:1, respectively, phase modulated onto a 1.024-MHz subcarrier. The subcarrier is frequency multiplexed with playback voice and three scientific data subcarriers at baseband. Even though the spacecraft recorder is limited to a 10^{-5} BER, the telemetry channel in the ground station has a 10^{-6} BER design requirement. This 10^{-6} BER requirement insures that the minimum BER (10^{-5}) obtained at the ground station is limited only by the spacecraft equipment. The input SNR (SNR_{in}) as shown in figure C-1 is therefore determined by the output power required in the 1.024-MHz bandpass filter for a 10^{-6} BER.

Expected performance of the Mode 2 telemetry channel with 32:1 playback of 1.6Kbps TLM is described by the BER versus SNR_{in} curves shown in figure C-2. The curves are plotted for frequency deviations (Δf) corresponding to best case (largest deviation), nominal case, and worst case conditions. The 8.0db FM threshold requirement is within 0.1db of the best case (largest Δf) input SNR required to achieve a 10^{-6}. BER. However, for worst case frequency deviations, an input SNR of 9.3db is required for the 10^{-6} BER. An 8db SNR yields a degraded 2.8×10^{-4} BER for worst case conditions.

Center frequency shifts of ±500 KHz (center frequency of the incoming FM signal from the CSM can vary by ±500 KHz because of spacecraft transmitter instabilities and Doppler effects) should degrade the PCM channel performance by 1 to 1.5db for Modes 1 and 2. This expected degradation was extrapolated from test data given in reference 3.

CSM FM Mode 3 provides 32:1 playback of LM 1.6Kbps split-phase telemetry modulated at baseband. This mode utilizes the 1-MHz prefilter noise bandwidth in conjunction with the 4-MHz loop noise bandwidth. The full 6db improvement in circuit margins due to the reduction in the effective input noise bandwidth from 4 MHz in Modes 1, 2, and 4 to 1 MHz in Mode 3 is not realizable because of frequency offsets. Signals through the 1-MHz bandwidth are especially sensitive to shifts in center frequency. The frequency shifts will result not only in a significant amount of signal energy falling outside the demodulator passband, but will also increase the impulse noise at the output.



▼ EXPECTED VALUE OF TOTAL RECEIVED POWER AT LUNAR DISTANCE USING *AN* 85-FOOT MSFN ANTENNA AND THE CSM HIGH-GAIN ANTENNA

* -102 dbm (WORST CASE)
** -99 dbm (NOMINAL AND BEST CASE)

Figure C-2. Expected BER Versus SNR_{in} for 32:1 CSM TLM, CSM FM Mode 2

The expected BER versus SNR_{in} curves are shown in figure C-3. A nominal 2db degradation from theoretical has been included to account for the degradation observed in the system tests. Effects of a 400-KHz offset frequency are also shown. Note that for the case of no frequency offset, the 8.0db FM threshold requirement meets the input SNR requirement for a 10^{-6} BER for best and nominal case conditions only.

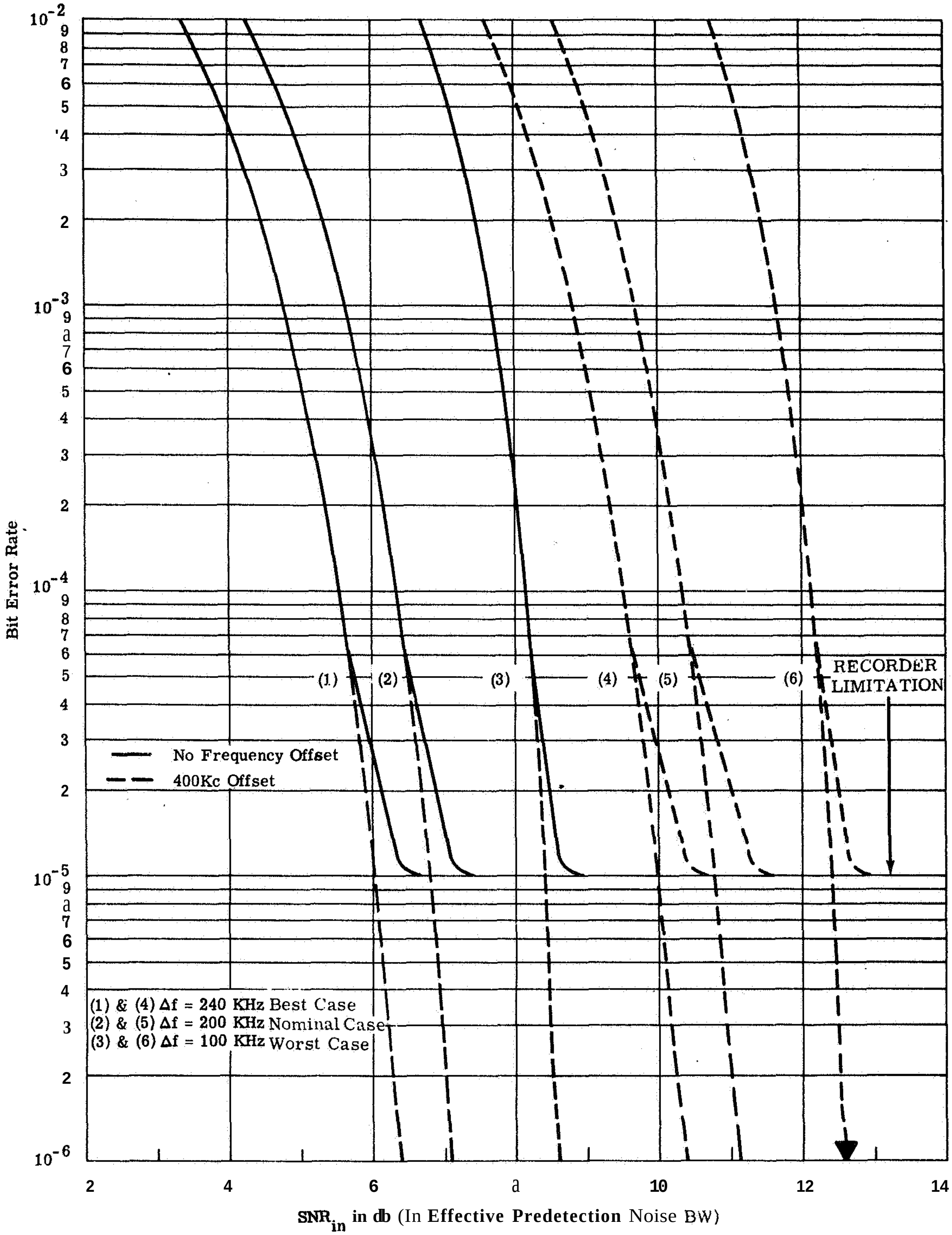
LM Telemetry

LM Modes 9 and 10 have real time 1.6Kbps or 51.2Kbps telemetry phase modulated onto a 1.024-MHz subcarrier. The telemetry subcarrier is then frequency multiplexed with a 1.25-MHz voice subcarrier and TV (only Mode 10 has TV). The input SNR requirement for the carrier frequency demodulator is determined by the output SNR needed to obtain a 10^{-6} BER in the telemetry channel.

The expected 51.2Kbps telemetry characteristics illustrated in figure C-4 are theoretical curves degraded by 2db. This 2db degradation is due to excessive stress in the FM demodulation loop and should not be confused with the telemetry degradation in the 1.024-MHz subcarrier demodulator and decommutation equipment. The nominal case 1.6Kbps telemetry curve (1) in figure C-4 is obtained from the experimental results. It is doubtful that the best case characteristics for 1.6Kbps telemetry will show any improvement over the experimental data since the carrier frequency demodulator will begin to lose phase lock below 3.5db. It can also be expected that some FM demodulators at the MSFN sites will be unable to hold lock at 3.5db. A worst case signal-to-noise requirement of 5.5db is used to account for these variations in demodulator performance. The output characteristics of the telemetry channel shown in figure C-4 indicate that an input SNR of 12.5db is required to achieve a 10^{-6} BER for the condition of worst case frequency deviation. The mode-as-a-whole requirement of 8db will result in an unacceptable 4×10^{-3} BER for 51.2Kbps telemetry.

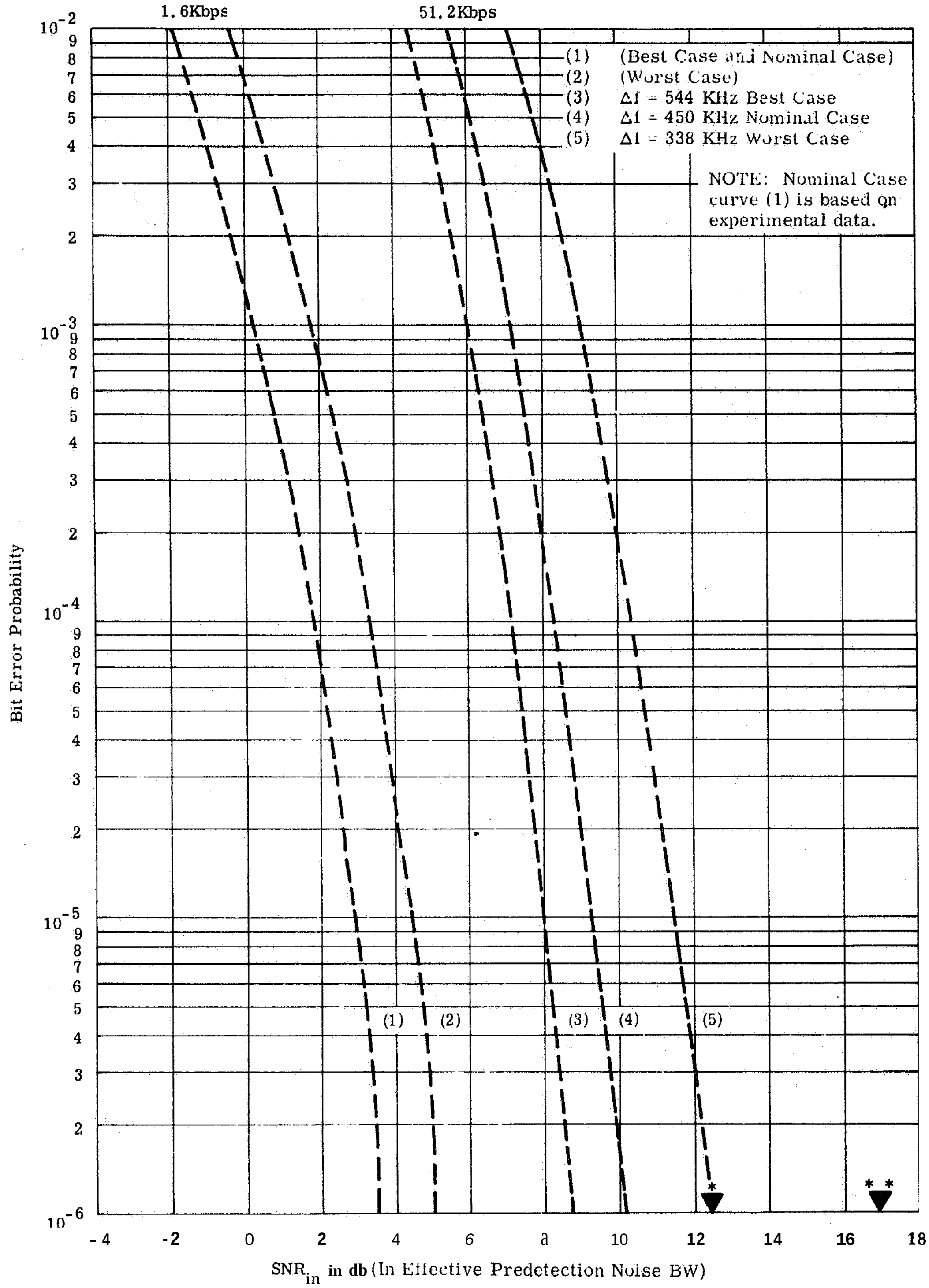
CSM Playback Voice

Playback voice at 1:1 and 32:1 is frequency modulated directly onto the carrier at baseband for FM Modes 1 and 2, respectively. Because of the close proximity of the scientific data channels, some interference noise from these channels will appear in the 90-KHz output voice bandwidth. This interference should not have any effect on the 1:1 playback voice. However, preliminary test data indicates considerable incidental frequency modulation effects exhibited by the demodulator below 1KHz will degrade the 1:1 playback voice. Tests are underway to determine the amount of voice degradation present for both the 32:1 and 1:1 playback conditions. No word intelligibility test data are currently available for comparison.



▼ EXPECTED VALUE OF TOTAL RECEIVED POWER AT LUNAR DISTANCE USING AN 85-FOOT MSFN ANTENNA AND THE CSM HIGH-GAIN ANTENNA [-102 dbm (WORST CASE)]

Figure C-3. Expected BER versus SNR_{in} for FM Mode 3 with 0 and 400 KHz Frequency Offsets, CSM Mode 3



▼ EXPECTED VALUE OF TOTAL RECEIVED POWER AT LUNAR DISTANCE USING AN 85-FOOT MSFN ANTENNA AND THE LM ERECTABLE ANTENNA

* -95.8 dbm (WORST CASE)

** -92.2 dbm (NOMINAL CASE)

Note: Best Case Value for SNR$_{in}$ is 19.1 db at a Total Received Power Level of -90.2 dbm.

Figure C-4. Expected BER Versus SNR$_{in}$ for LM Modes 9 and 10 Using Performance and Interface Specification Parameters

The expected output characteristics, SNR_{out} versus SNR_{in}, for Mode 2 using P&I Specification parameters are shown in figure C-5. The output SNR requirement is 14db for 90% word intelligibility, assuming 12db clipping and no preemphasis. (This 14db requirement is true only for a Gaussian type input noise spectrum. When the 14db output SNR level is below FM threshold, impulse noise may severely degrade the voice intelligibility. The effects of impulse noise below FM threshold are currently under investigation at MSC.) Assuming that the output SNR requirement is 14db regardless of FM threshold, the required SNR_{in} for playback voice are, from figure C-5, 9.7db, 10db, and 10.7db, respectively, for best case, nominal case, and worst case frequency deviations. Note that the 8.0db mode-as-a-whole requirement is well below the input SNR required for acceptable voice.

Frequency offsets should produce little degradation to the analog-type playback voice at baseband. Degradations due to frequency offsets are limited mainly to the telemetry channels.

LM Voice

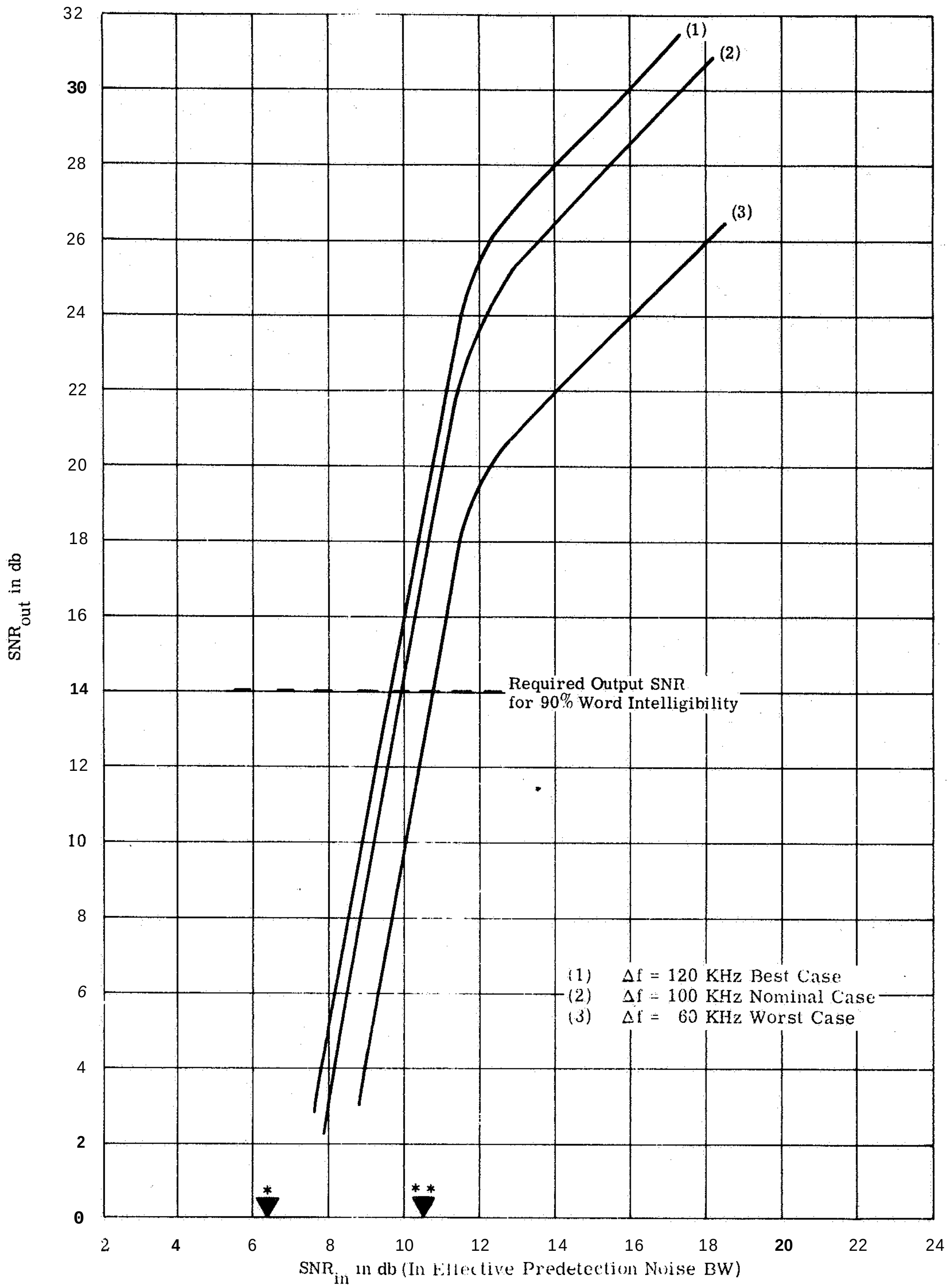
LM FM Modes 9 and 10 have real-time voice frequency modulated onto a 1.25-MHz subcarrier which is frequency multiplexed with the telemetry subcarrier and baseband TV. This composite signal is then modulated onto the S-band carrier. The required input SNR for voice is determined by the output SNR (14db, RMS signal to RMS noise) needed to obtain 90% word intelligibility.

Figure C-6 depicts the expected SNR_{out} versus SNR_{in} transfer characteristics for the total FM/FM system; i.e., through two cascaded FM demodulators. These curves consider only the variations in peak frequency deviation, as listed in the LM P&I specifications, for distinguishing the various operating conditions. The input SNR required in order to obtain a 14db output SNR is 7db for the best case, 9.2db for the nominal case, and 11.3db for the worst case operating conditions. At the specified 8.0db input threshold level, the nominal and worst case output performances are severely degraded.

It should be noted that the 14db output SNR level occurs below FM threshold. The remarks in the CSM Playback Voice section regarding impulse noise degrading voice intelligibility are also applicable for the LM voice channel.

CSM Television

Television at baseband is the only information transmitted on CSM FM Mode 4. The required output SNR for television is 19db, RMS signal to RMS noise. Test results indicate that the optimum predetection - loop filter bandwidth configurations are 4 - 11 MHz for LM and unfiltered - 4 MHz for CSM.

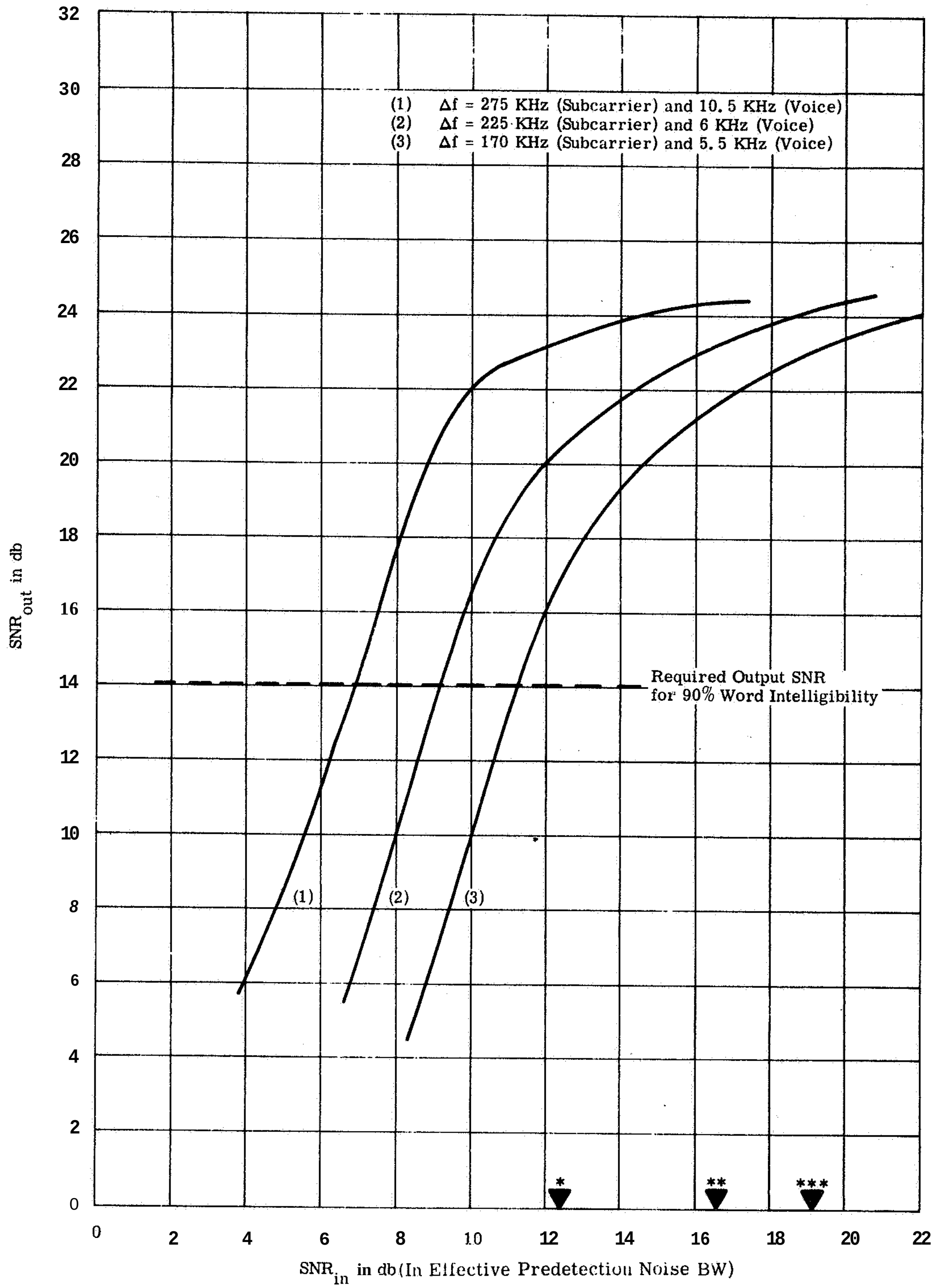


▼ EXPECTED VALUE OF TOTAL RECEIVED POWER AT LUNAR DISTANCE USING AN 85-FOOT MSFN ANTENNA AND THE CSM HIGH-GAIN ANTENNA.

* -102 dbm (WORST CASE)

** -99 dbm (NOMINAL AND BEST CASE)

Figure C-5. Expected SNR_{out} Versus SNR_{in} Characteristics for CSM 32:1 Playback Voice, CSM Mode 2



▼ EXPECTED VALUE OF TOTAL RECEIVED POWER AT LUNAR DISTANCE USING AN 85-FOOT MSFN ANTENNA AND THE LM ERECTABLE ANTENNA

* -95.8 dbm (WORST CASE)
** -92.2 dbm (NOMINAL CASE)
*** -90.2 dbm (BEST CASE)

Figure C-6. Expected Transfer Characteristics, SNR_{out} Versus SNR_{in} for the Voice Channel Using Frequency Deviations as listed in the P&I Specification, LM Mode 9 or 10

In the CSM configuration the loop does the actual signal filtering. However, in the LM modes, test results indicate considerable distortion, and hence, degradation occurs in the unfiltered - 4 MHz configuration. This distortion is due to the large instantaneous frequency error caused by the simultaneous voice, telemetry, and television modulation. The larger 11-MHz loop filter minimizes the distortion and should be used with the 4-MHz predetection filter for receiving LM FM signals. If the LM configuration is used for the CSM, a 0.5db degradation will result. The expected SNR_{out} versus SNR_{in} characteristics using frequency deviations as listed in the CSM/LM P&I Specifications are shown in figure C-7. The picture quality is degraded by frequency offsets when using the 4 MHz - 11 MHz combination, but little degradation occurs for the unfiltered - 4 MHz combination, However, the 4 MHz - 11 MHz combination provides better picture resolution at center frequencies. Three television pictures are available for comparison in figures C-8, C-9, and C-10. The input SNR conditions are, respectively, 5db and 9db with no frequency offsets and 5db with a 500-KHz frequency offset. The pictures were generated by a TV test set and do not include any camera or lighting degradation.

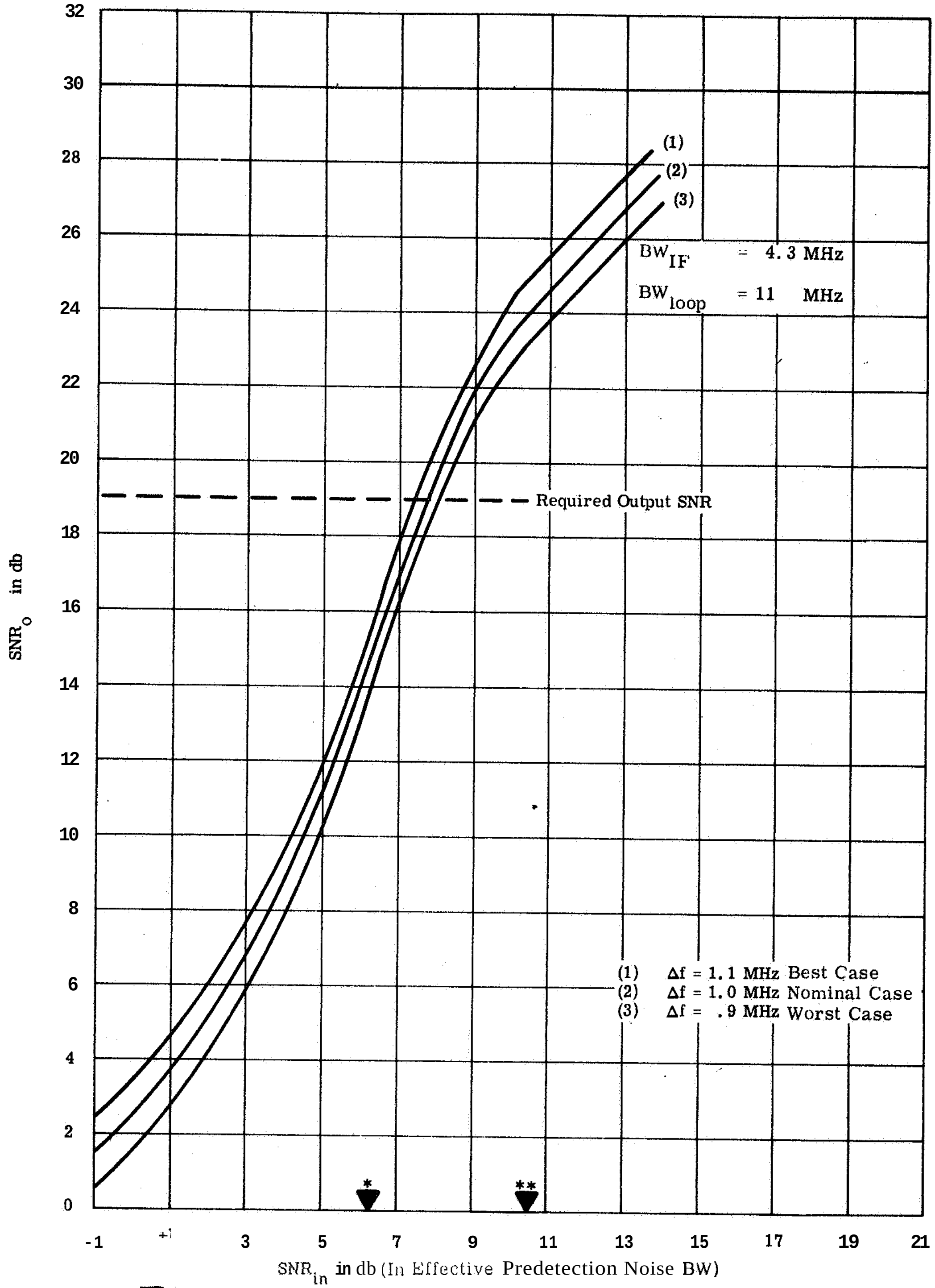
LM Television

Television is transmitted at baseband on LM Mode 10, together with voice and telemetry subcarriers. The required output SNR for television is specified as 19db, RMS signal to RMS noise. Effects of the voice and telemetry subcarriers on the TV channel SNR characteristics are negligible. This is in contrast to the FM telemetry channel which is degraded by 2db in the presence of voice and television.

The 4 MHz - 11 MHz bandwidth configuration in the carrier frequency demodulator has an experimental 1.6db advantage over the unfiltered - 4 MHz configuration. Close agreement exists between experimental and theoretical results for SNR tests in the television channel.

The expected SNR output characteristics are shown in figure C-11. The 19db output SNR requirement is obtained at input signal levels lower than the 8db mode-as-a-whole requirement. The television channel will be the last of the services on the FM modes to fail as signal power is reduced.

The expected television picture quality for input SNR's of 7db and 5db are shown in figures 6-12 and C-13, respectively. These pictures are gray scale patterns generated by a TV test set and do not include any camera or lighting degradation.



▼ EXPECTED VALUE OF TOTAL RECEIVED POWER AT LUNAR DISTANCE USING AN 85-FOOT MSFN ANTENNA AND THE CSM HIGH-GAIN ANTENNA.

* -102 dbm (WORST CASE)

** -99 dbm (NOMINAL AND BEST CASE)

Figure C-7. Expected SNR_{out} Versus SNR_{in} Characteristics for CSM Television Using P&I Specification Parameters, CSM Mode 4

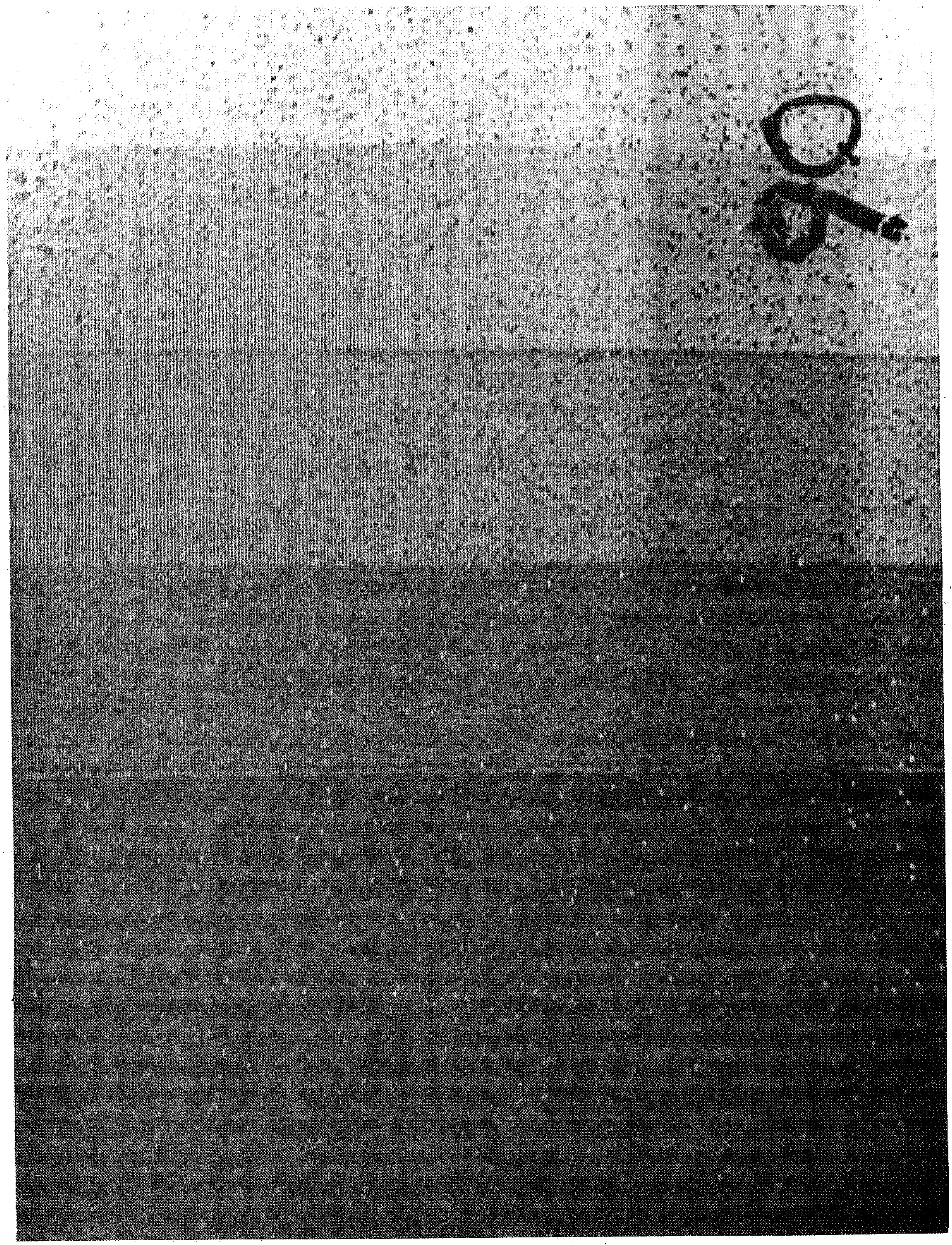


Figure C-8. CSM Television Picture Quality for SNR_{in} = 5db, SNR_{out} = 10db, No Offset Frequency, and a 4-MHz - 11-MHz Bandwidth Configuration

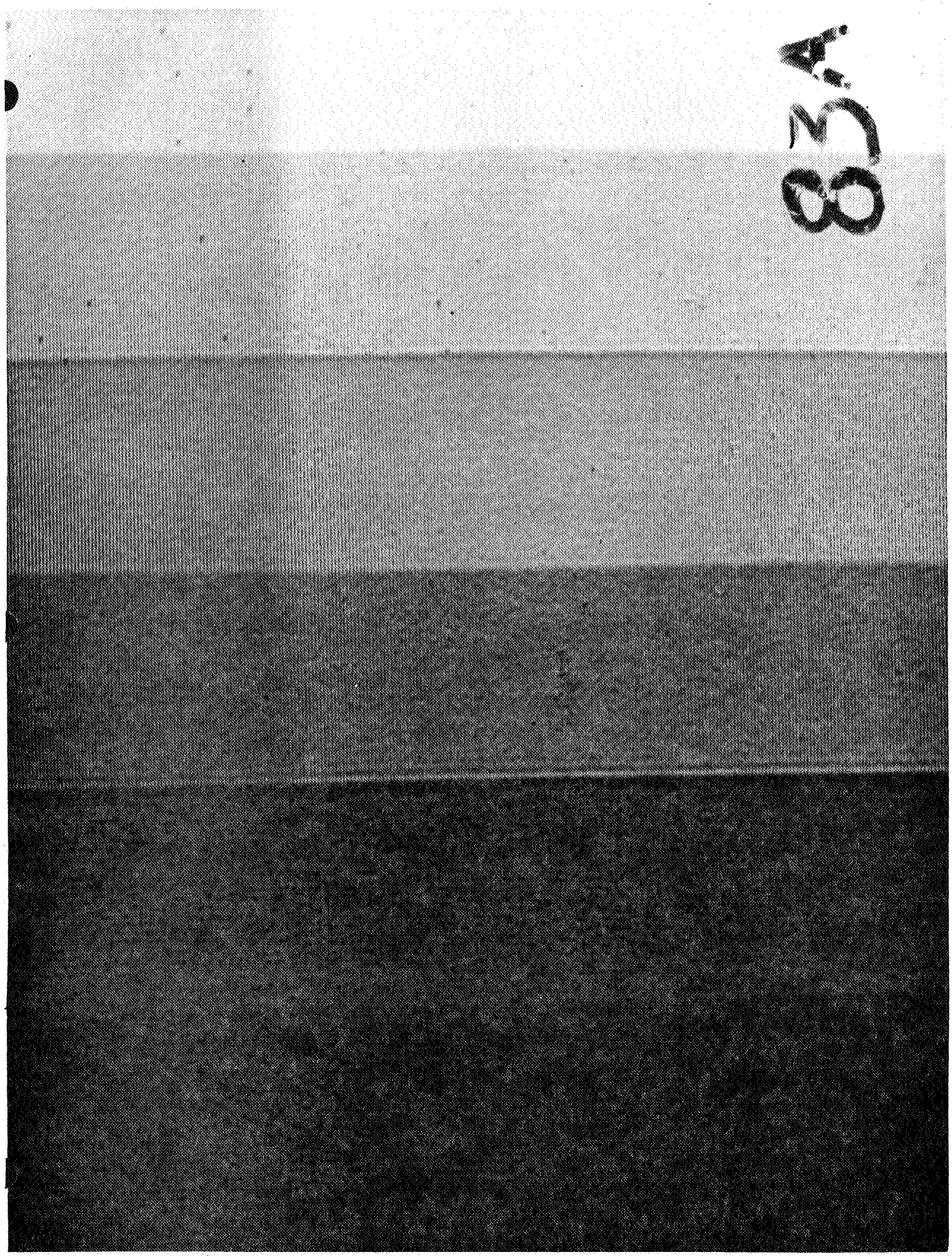


Figure C-9. CSM TV Picture Quality for SNR_{in} = 9.0db; SNR_{out} = 21db, No Offset Frequency, and a 4-MHz - 11-MHz Bandwidth Configuration

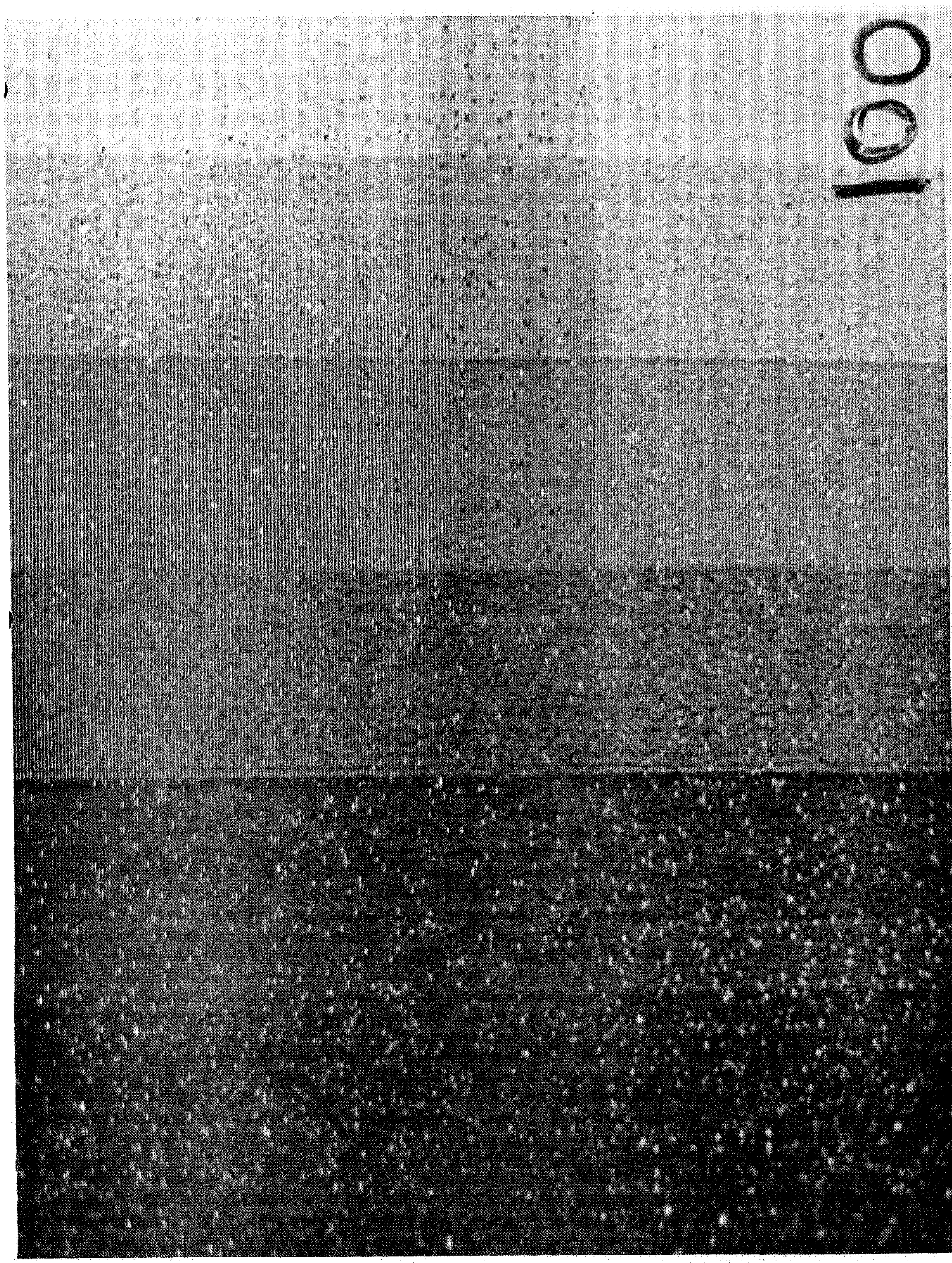
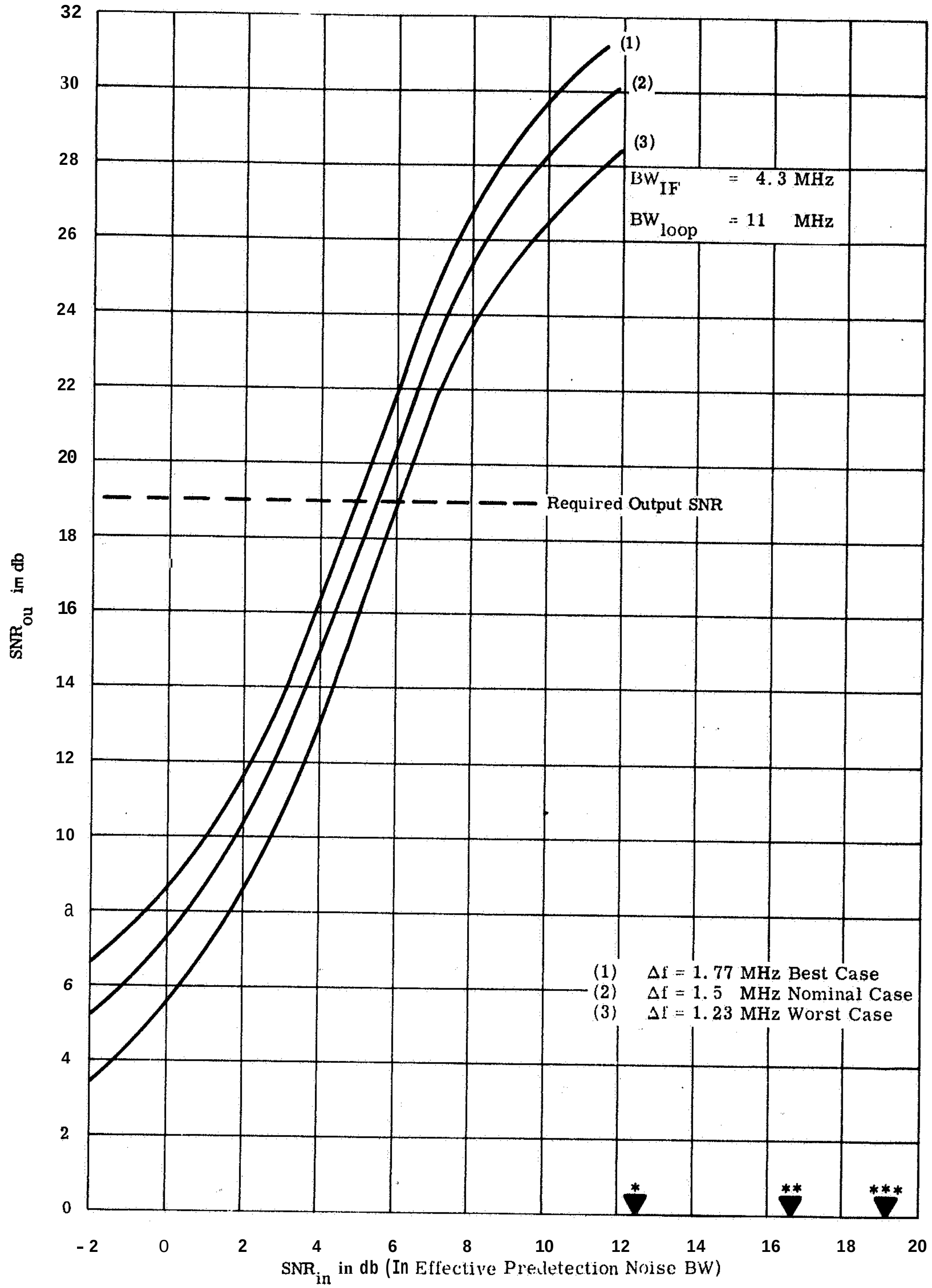


Figure C-10. CSM TV Picture Quality for SNR_{in} = 5.0db; SNR_{out} = 8.9db, +500-KHz Offset Frequency, and a 4-MHz - 11-MHz Bandwidth Configuration



▼ EXPECTED VALUE OF TOTAL RECEIVED POWER AT LUNAR DISTANCE USING *AN* 85-FOOT MSFN ANTENNA AND THE LM ERECTABLE ANTENNA

* -95.8 dbm (Worst Case)
** -92.2 dbm (Nominal Case)
*** -90.2 dbm (Best Case)

Figure C-11. Expected SNR_{out} Versus SNR_{in} Characteristics for LM Television Using P&I Specification Parameters

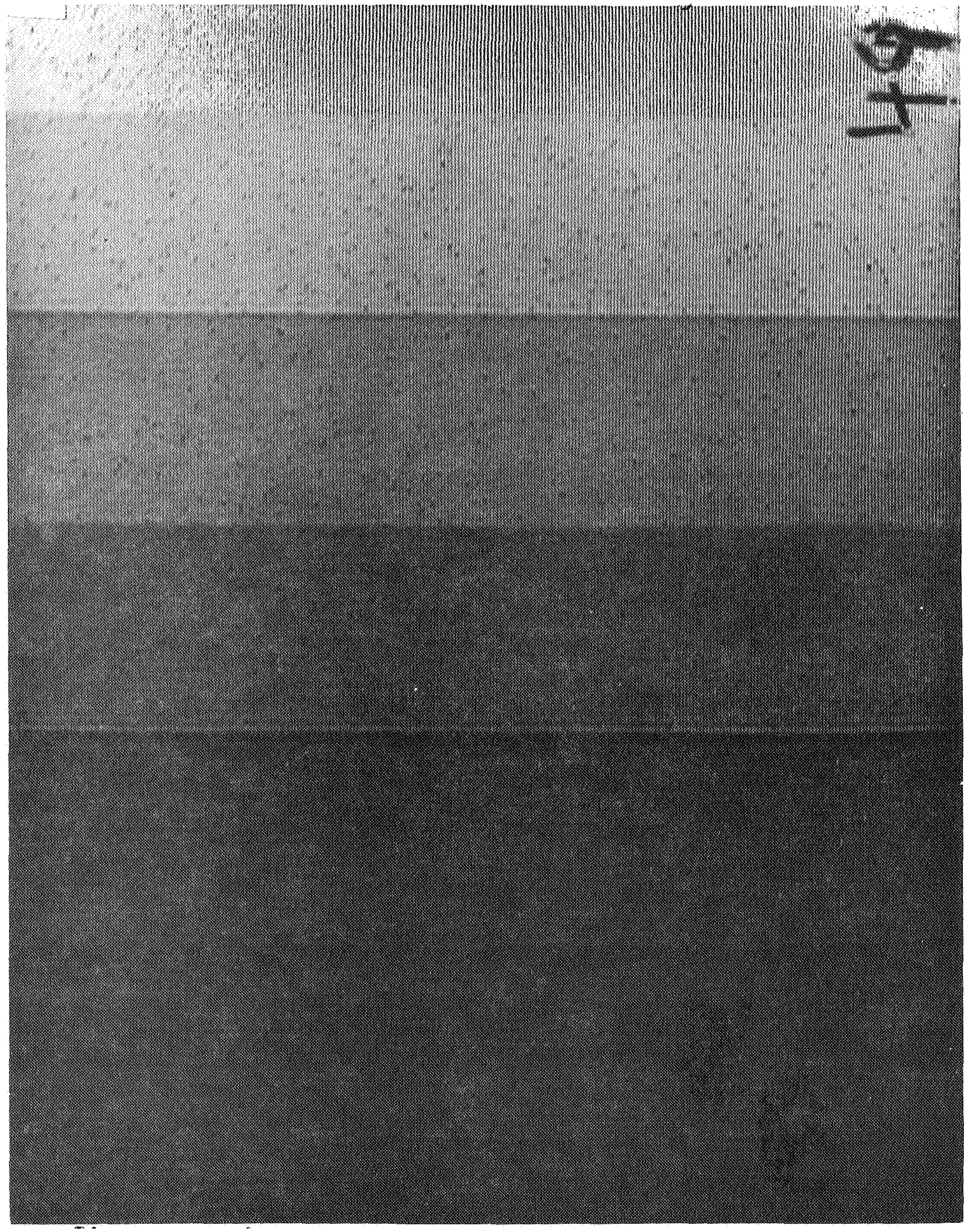


Figure C-12. LM Television Picture Quality for SNR_{in} = 7.0db, SNR_{out} = 20.5db, Voice and TLM Subcarriers Present, No Offset Frequency, and a 4-MHz - 11-MHz Bandwidth Configuration

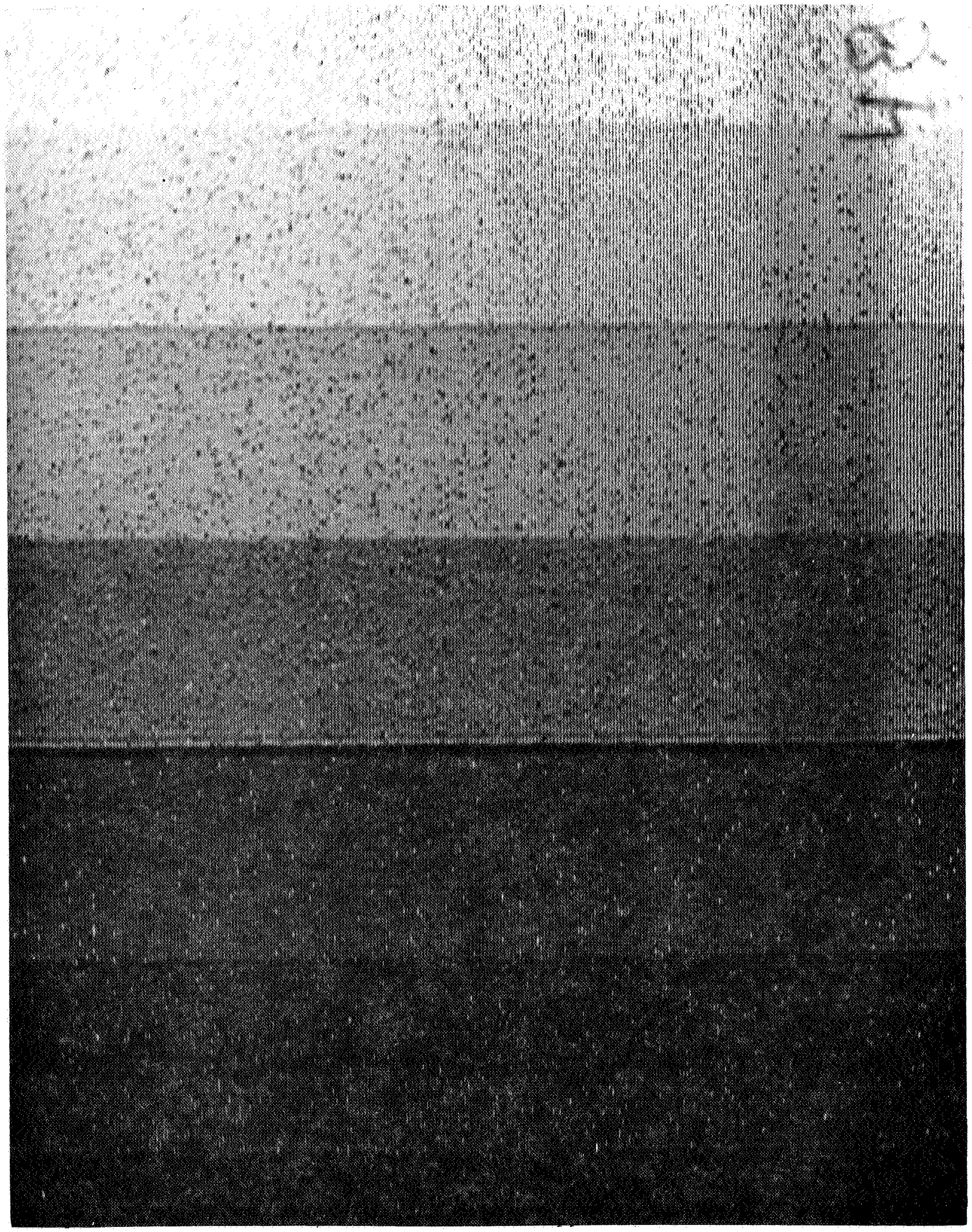


Figure C-13. LM TV Picture Quality for SNR_{in} = 5. Odb; SNR_{out} = 14. Odb, Voice and TLM Subcarriers Present; No Offset Frequency, and a 4-MHz - 11-MHz Bandwidth Configuration

Summary

The input SNR's required to provide the necessary output performance for the **CSM** and **LM FM** modes are summarized on page **C-20.** **As** can be seen from the data, the 8db mode-as-a-whole **SNR** does not necessarily give the required output performance. It should also be noted that in all cases except the **CSM** 1:1 playback voice service and **LM** TV service, expected performance is below that predicted by theoretical curves. These theoretical curves are for an ideal conventional discriminator. Phase lock loop discriminators should perform better than, and certainly no worse than, conventional discriminators.

Several methods for improving **FM** channel performance are under investigation. Analysis and test results indicate that all services can be improved to perform in accord with theoretical (ideal conventional discriminator) by providing automatic frequency control **(AFC)** in the **FM** channel of the **MSFN** receiver and implementing means to minimize stress in the **FM** demodulator phase-locked loop. However, to ensure positive circuit margins, it is necessary to improve the **FM** link by 1.5db and to increase the **CSM** playback voice deviation. **As** a step toward achieving this improvement, reduction of spacecraft cable losses (to improve the effective radiated power) and improvement of the worst case gain (50.5db) for the 85-foot antennas have been officially requested of **NAA** and **GSFC** respectively.

Service	Output Performance Requirement	Required Input SNR (Based on Expected Performance Curves)			*Deviation (Hor ntal Shift) of Expe d Performance C es from Theoretical urves			Actual Margins		
		Best Case	Nominal Case	Worst Case	Best Case	Nominal Case	Worst Case	Best Case	Nominal Case	Worst Case
I. CSM										
CSM Telemetry 51.2Kbps										
(1:1 Playback)	10^{-6} BER	6.9db	7.7db	8.3db	-1db	-1db	-1db	-0.3db	-1.1db	-1.7db
(32:1 Playback)	10^{-6} BER	7.9db	8.7db	9.3db	-2db	-2db	-2db	-1.3db	-2.1db	-2.7db
Playback LM Split-Phase Telemetry (32:1 Playback)	10^{-6} BER	6.4db	7.1db	8.6db	-2db	-2db	-2db	+6.2db	+5.5db	+4.0db
With 400 KHz offset frequency	10^{-6} BER	10.4db	11.1db	12.6db	-8db	-6db	-6db	+2.2db	+1.5db	0
Playback Voice 32:1 Playback	SNR_o = 14db based on 90% intelligibility	9.7db	10.0db	10.7db	-2db	-2db	-2db	-3.1db	-3.4db	-4.1db
1:1 Playback	SNR = 14db requirement	7.7db	8.0db	8.7db	0db	0db	0db	-1.1db	-1.4db	-2.1db
TV	SNR_o = 19db	7.4db	7.8db	8.1db	-1db	-1db	-1db	-0.8db	-1.2db	-1.5db
II. LM										
Telemetry 51.2Kbps	10^{-6} BER	8.7db	10.2db	12.5db	-2db	-2db	-2db	+3.6db	+2.1db	-0.2db
1.6Kbps	10^{-6} BER	3.5db	3.5db	5.5db				+8.8db	+8.8db	+6.8db
Voice	SNR_o = 14db (based on 90% intelligibility requirement)	7.0db	9.2db	11.3db	-3db	-3db	-3db	+5.3db	+3.1db	+1.0db
TV	SNR_o = 19db	5.0db	5.5db	6.1db	0db	0db	0db	+7.3db	+6.8db	+6.2db

*A minus sign indicates that the expected curve is shifted to the right, i.e., performance is degraded.

APPENDIX D

DISCUSSION OF BU VOICE INTERFERENCE IN THE 1.6Kbps TLM CHANNEL

This appendix is intended to show the rather severe discrepancies between predicted and measured TLM performance in PM modes which contain TLM modulated onto a 1.024-MHz subcarrier and BU voice modulated directly onto the carrier. Based on test results in the Electronic Systems Compatibility Laboratory in ISD, theoretical calculations for these modes appear to be quite optimistic. The data presented here was obtained from the LM Gross Compatibility Test Program.

Figure D-1 shows the predicted and measured TLM BER performance as a function of total received power for LM Mode 4. When the baseband voice channel is modulated with a noisy voice signal, the minimum BER of the TLM channel is severely limited. The 50-Hz carrier loop noise bandwidth configuration gives the best BER performance; however, the signal level required to achieve a 10^{-3} BER is 3 db greater than predicted. Thus, a 3 db degradation in the calculated circuit margin for 1.6 Kbps telemetry is possible.

Use of the 700-Hz carrier loop noise bandwidth results in a lower limit of 10^{-3} on the BER. This 10^{-3} BER is achieved only at totally unacceptable received power levels.

Degraded TLM performance also appears in CSM and LM modes 8., which have 1.6 Kbps TLM with voice at baseband. The BU voice signal at baseband appears as noise in the carrier loop of the receiver. This noise appears as phase jitter on the reference signal and in the coherent detection process in the MSFN receiver. It has also been noted that an additional low-pass filter inserted in the receiver's carrier loop to reduce false-lock problems increases telemetry degradation.

The modulation index of the voice signal onto the S-band carrier has been shown to be a critical parameter for determining the extent of the telemetry degradation. Additional testing and analysis is presently underway to determine if a parameter optimization procedure will improve performance of the BU voice/TLM modes.

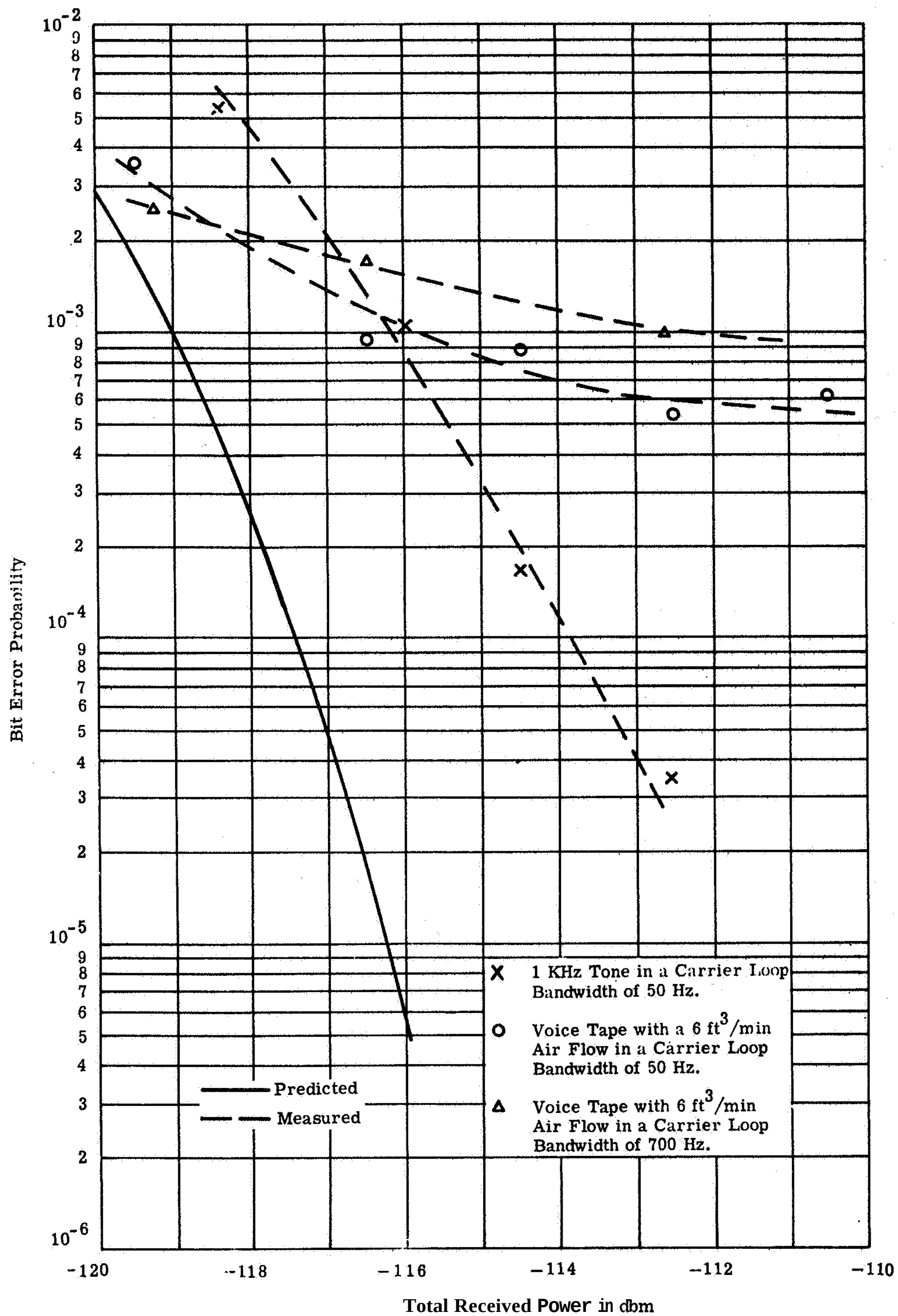


Figure D-1. Predicted and Measured TLM BER Performance as a Function of Total Received Power for LM Mode 4

APPENDIX E

SECOND-ORDER CIRCUIT MARGIN DEGRADATIONS

IPM Effects

Incidental phase modulation (IPM) of the down-link S-band carrier resulting from structural vibration, power supply ripple, and other similar pertubations acts as band-limited noise at the input to the spacecraft PM modulator. This IPM will appear as noise on the coherent carrier reference in the MSFN receiver. Analysis and test data indicate that significant amounts of this narrow-band noise will degrade communication performance, particularly telemetry bit error rates (BER).

Because of the many contributing sources of IPM and the difficulty in determining what level to specify for each source, a total allowable system specification is necessary. An effort was initiated at MSC to determine the maximum allowable level to be imposed on the SC contractors as a total system specification. The criteria used to define the maximum allowable IPM was based on accepting not more than 2db degradation of the telemetry 10^{-4} BER threshold. Based on this criteria, test data showed that not more than 28 degrees RMS IPM with constant spectral density in a band from 20 Hz to 5 KHz could be allowed. To ensure minimum degradation of the down-link PCM data, MSC requested NAA (RID I-4-12, Block II CDR, Part I) and GAEC (RFC #H-4, LM CDR, Part 2) to add this new requirement to the LM and CSM P&I specification. This value was negotiated with NAA and GAEC and was subsequently analyzed by the SC contractors and included in the LM and CSM-MSFN S-Band Performance and Interface Specifications, LSP 380-17 and SID 64-1613, respectively. The evaluation by NAA (TDR 66-22) determined that the total S-band system phase jitter' expected, due to the antenna system, S-band power amplifier, USBE, transmission line, and RF tracking system, will be 5.35 degrees RMS. Since the initial value of total system IPM was imposed on GAEC, the LM's specified value has been reduced to 20 degrees RMS.

Figure E-1 gives the LM test results which show the measured BER for various IPM levels. The relative degradation to the LM PCM channel performance is shown in figure E-2.

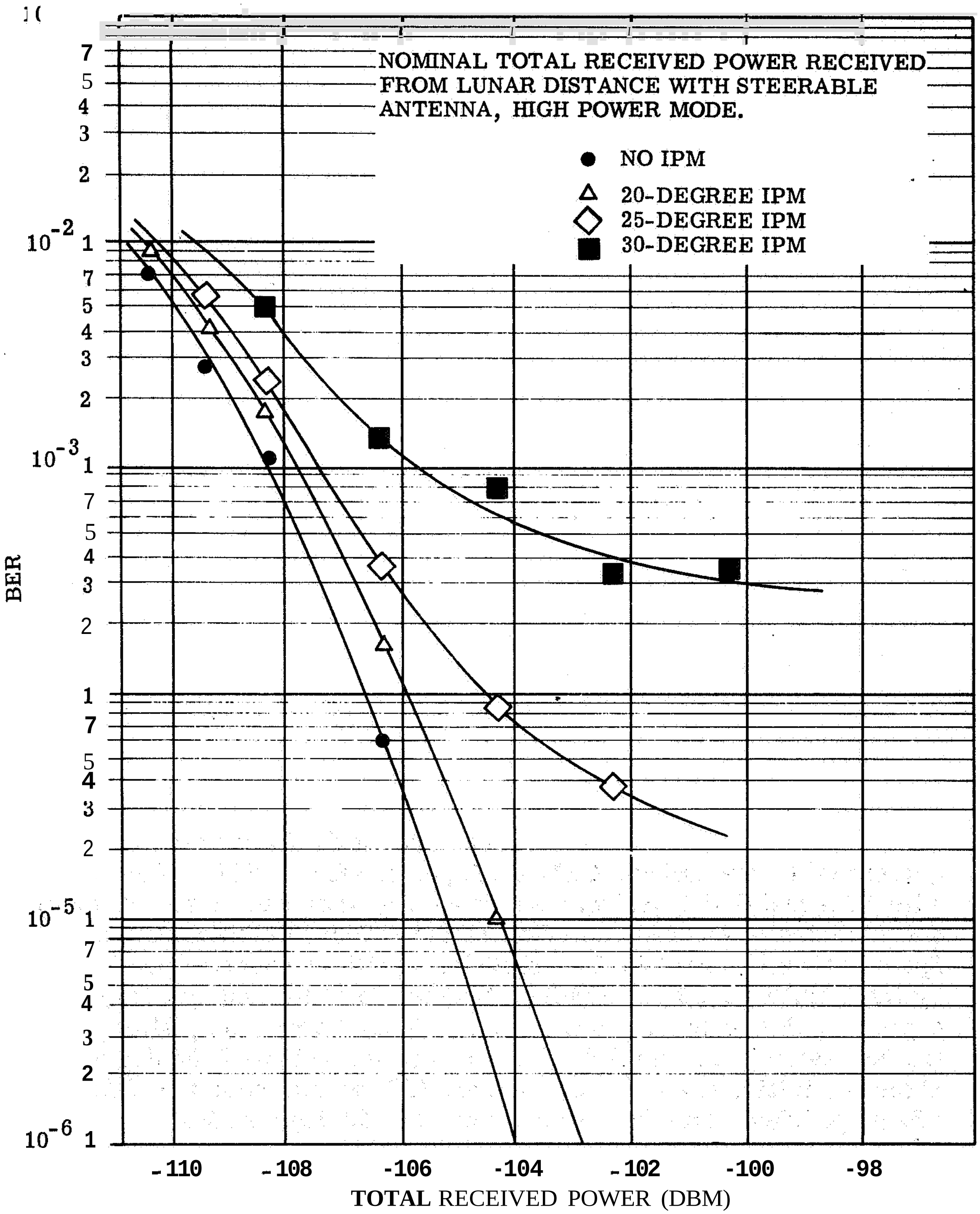


Figure E-1. BER Versus Total Received Power for Various IPM Levels @own-Link Mode 1 - 51.2-Kbps Bit Rate)

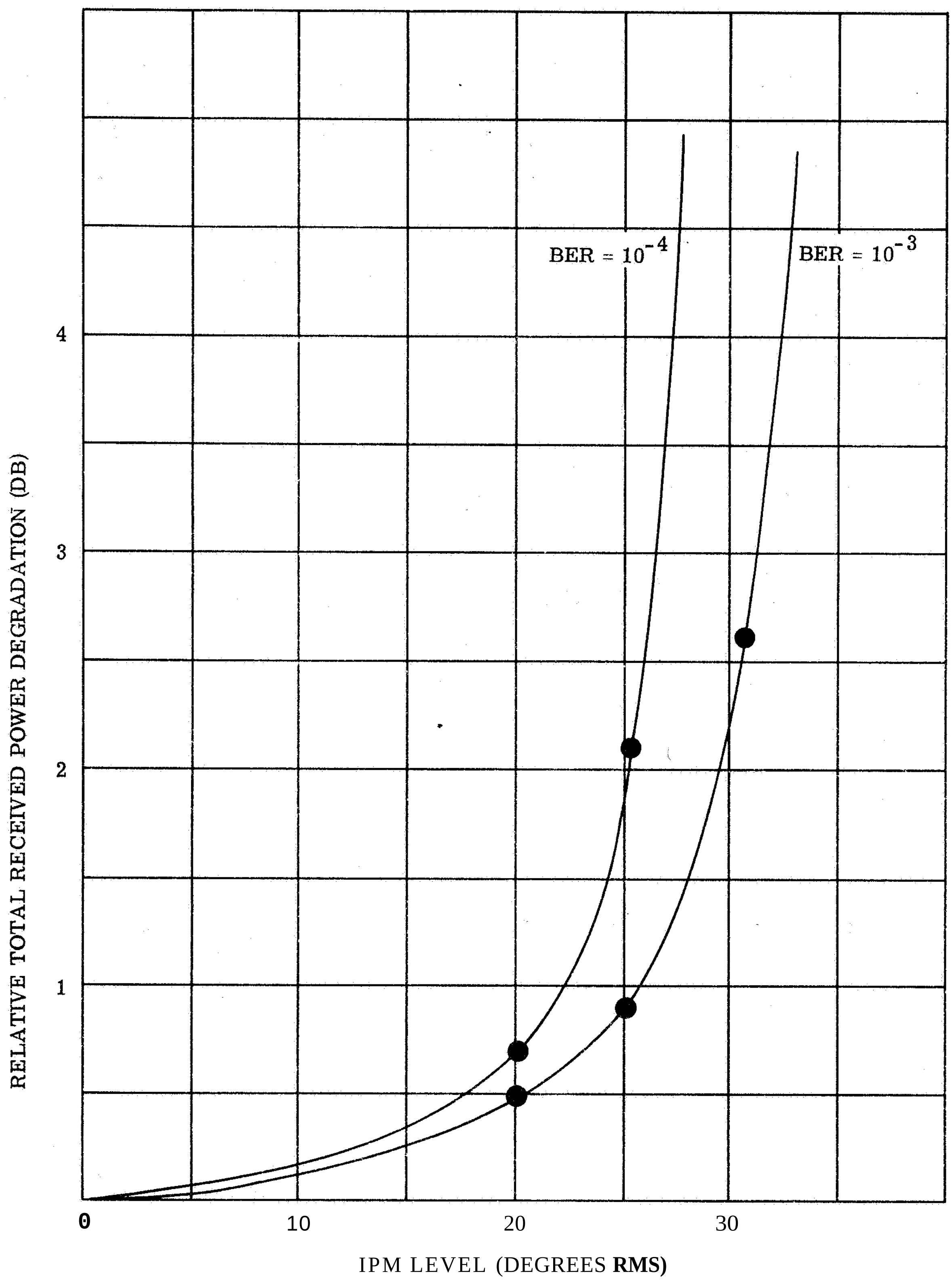


Figure E-2. Relative Degradation of PCM Channel Performance Versus IPM Level for 10^{-3} and 10^{-4} BER (LM Down-Link Mode 1 - 51.2-Kbps Bit Rate)

Effects of Finite Transmitted Signal-to-Noise Ratios (SNR_T) on Circuit Margins

Circuit margin calculations are made assuming an infinite transmitted signal-to-noise ratio (SNR_T), i.e., a thermal predetection signal-to-noise ratio (SNR_R) based only on thermal noise contributed by the RF link is used in the circuit margin calculation. In general, this assumption is valid only when SNR_T is greater than 25db. For SNR_T less than 25db, the effective predetection signal-to-noise ratio (SNR_{eff}), which is a signal-to-(thermal noise + transmitted noise) ratio, is degraded from the calculated SNR_R.

To evaluate the effects of this degradation on circuit margins as presently calculated, consider the combination of two SNR in the predetection bandwidth of a communication channel. The maximum possible SNR_{eff} corresponds to the lower of the two SNR present. This maximum occurs only when the higher SNR is infinite. For any other value, the lower SNR is degraded.[6] Figure E-3 shows this degradation as a function of the difference between the higher and lower SNR. This curve can be used to determine the circuit margin degradation in a particular channel due to a finite SNR_T.

In general, the amount of degradation depends on the specific circuit margin value considered. For example, assume that the SNR_R in the 51.2Kbps TLM channel is 8.5db which is the required value for a 0db circuit margin. If the SNR_T is 15db, the SNR_T - SNR_R difference is 6.5db. Using figure E-3, it is noted that the effective predetection SNR_{eff} is 7.57db (8.5db - 0.93db). Thus, the 0db circuit margin is degraded 0.93db. If SNR_R is 15db, which corresponds to a 6.5db circuit margin, the degradation to the effective predetection SNR due to a 15db SNR_T is 3db. Thus, the circuit margin of 6.5db is degraded by 3.5db. For situations where the SNR_T is less than the channel requirement, the circuit margin is degraded by the amount SNR_T is less than the requirement, plus the degradation to SNR_T determined from figure E-3.

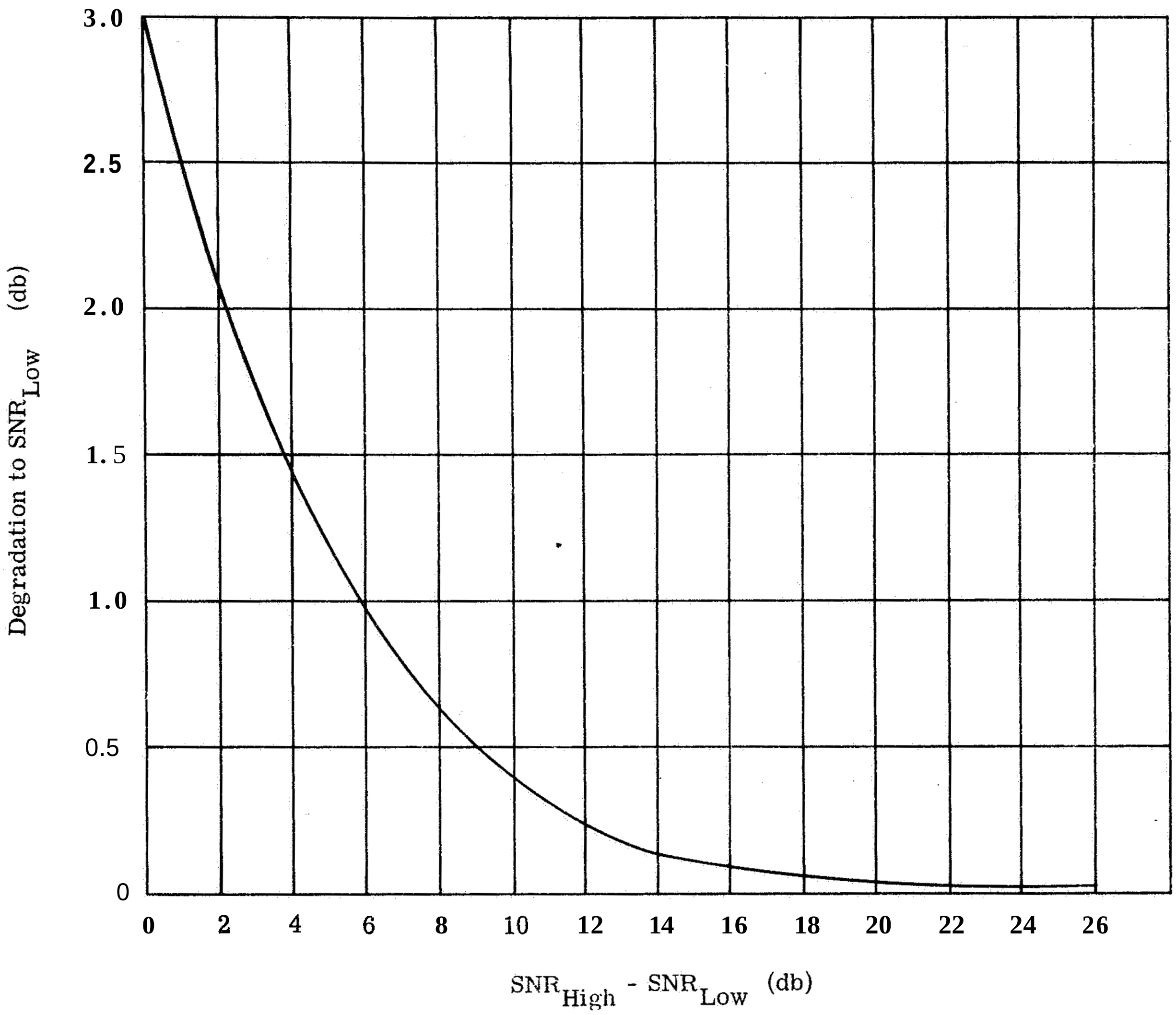


Figure E-3. Degradation in Received SNR Due to Finite Transmitted SNR Ratio

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